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METHODOLOGY INVESTIGATION

FINAL REPORT

ADVANCED RADAR TESTING TECHNIQUES II

BY
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MEMORANDUM FOR: Commander, U.S. Army Electronic Proving Ground, ATTN: STEEP-ET-U, Fort Huachuca, AZ 85613-7110

SUBJECT: Transmittal of Final Report - Methodology Investigation Advanced Radar Testing Techniques (II), TECOM Project No. 7-CO-R88-EPO-007

1. Subject report is approved.

2. Point of contact, this headquarters, is Mr. Richard V. Haire, AMSTE-TC-M, amstetcm@apg-emh4.apg.army.mil, AV 298-3677/2170.

FOR THE COMMANDER:

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The objective of this methodology investigation was to provide a detailed instruction set for the purpose of planning and conducting system level testing of advanced radars at USAEPG. The objective of this methodology investigation has been realized by the preparation of detailed instructions for performing system level testing of radar system characteristics. The methodology report specifies measurement instructions for modern radar parameters including ultra low sidelobes, probability of intercept, velocity response, target acquisition time, digital subsystem response, antenna beam forming control, and radar data processing.
Test measurement accuracy issues have been discussed and error analyses have been provided. Recommendations for radar test facility improvements and for Test Operations Procedures (TOPs) have been included in the report.
The analysis has provided needed methodology for the USAEPG to support the future testing of weapons location radars, search and acquisition radars, and battlefield surveillance radars.

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FOREWORD

The U.S. Army Electronic Proving Ground (USAEPG) initiated a two-part investigation to identify necessary actions required to fulfill the mission of testing present and future radar systems. The first phase of the effort has been completed and has provided a requirements analysis of the USAEPG.

This final report covers the second phase, and presents a detailed methodology for radar system testing. This report was prepared by ANRO Engineering Consultants, Inc., Lexington, Massachusetts. The technical expertise at ANRO was provided by Mr. David K. Barton, Vice President for Engineering, and by senior staff engineers Mr. Robert N. Maglathlin, Dr. Joseph D. DeLorenzo, and Mr. Edwin R. Hiller.

1. Summary

The Advanced Radar Testing Methodology Investigation (II), described in this report, was a continuation of work performed at the U.S. Army Electronics Proving Ground during 1987 [1]. In this second phase, the emphasis was placed on testing of radar system performance parameters, for which a combination of subsystems or a complete radar system operating in a realistic electronic environment is required. The system performance parameters are defined by the equipment specification, and the test procedures described in this report are designed to establish the degree to which the system under test satisfies the specification.

The general approach to system-level testing is addressed in Section 2.1. This is followed by general descriptions of an advanced radar and its critical subsystems, in Section 2.2, and system test procedures, in Section 2.3. In Sections 2.4, 2.5 and 2.6, test methodology and procedures are developed for general radar application, the procedures covering both closed-loop testing of combinations of subsystems, and field testing of the complete radar.

A list of references resource material used in the investigation is included at the back of the report.

In order to make the test procedures more specific, several radar system examples, synthesized to represent actual testing problems without use of actual classified military equipment, are described in Section 2.7. Test procedures developed for the general case are applied to these radar examples in Section 2.8, and specific comments are made on special problems and requirements for testing of these systems. Requirements for test data recording and evaluation are addressed in Section 2.9, and test equipment and facilities are discussed in Section 2.10. Conclusions and recommendations, including requirements for new Test Operation Procedures, are given in Section 2.11.

2. Details of Investigation

2.1 Philosophy of System-Level Testing

2.1.1 Radar System and Subsystem Specifications

The first step in development of a radar system to meet a given performance specification is to interpret this specification in terms of subsystem design parameters: e.g., transmitter power and waveform, antenna gain and beamwidth, receiver noise factor and frequency response, and signal processor characteristics. This interpretation is performed by the system engineer (normally during the contract definition phase, as part of the contractor's study effort). During development and assembly of the prototype radar, testing is carried out by the contractor and the government on critical components, circuits, and subsystems to determine that these portions of the system will support the roles assigned to them by the interpretation of the system specification. Standardized Test Operation Procedures are available which guide test personnel in performing and interpreting these tests. Many of the subsystem characteristics covered by this phase of testing are listed in Section 2.2 of this report.

2.1.2 System-Level Testing

Following successful testing of individual subsystems, the radar is assembled into an operating prototype system, on which some testing will normally be performed at the development laboratory or contractor's facility. These tests may include operation in the physical environments covered by the specification (e.g., temperature, moisture, vibration), and limited tests of performance. However, the ability of the radar to meet its over-all system performance specification can only be evaluated by tests of the entire system in the field environment, which includes a realistic electronic environment (e.g., moving targets, clutter reflections, interfering signals, and possibly attempts at ESM intercept of the radar signals).

The purpose of the investigation reported here is to define the process by which this system-level testing can be planned, carried out, and evaluated, and to identify facilities and equipment which may be required. The test requirements will be governed by the overall system performance specification, not necessarily by interpretations of this specification used in subsystem design. Detailed testing of individual subsystems is not required in the process, although a validation of certain subsystem characteristics may be desirable in order to diagnose shortfalls in system performance.

The emphasis on field tests of the over-all system does not exclude the use of closed-loop tests utilizing portions of the system (e.g., the combined receiver and digital subsystems). Such tests can support the field tests by evaluating more thoroughly and efficiently certain performance parameters. Both closed-loop and system field tests will be described in this report.

2.2 Radar System Performance Specifications and Characteristics

2.2.1 Radar Subsystems

The block diagram of a typical coherent radar system is shown in Figure 2.2.1. The major subsystems are:

- **Antenna**: The interface with the target and the surrounding environment. This subsystem includes the antenna and antenna control unit.

- **Transmitter**: The source of target illumination. This subsystem includes the transmitter/modulator, duplexer, waveform generator, and master oscillator/exciter.

- **Receiver**: The amplifier and initial filter for selection of target echoes. This subsystem includes the RF amplifier, mixers, IF amplifier, and detectors.

- **Digital Subsystem**: A group of special and general purpose processors which may perform the final stages of signal processing, data processing on selected targets, radar control, and antenna control. This subsystem includes the A/Ds, digital signal processor, data processor, control bus, plus the displays and controls.

The major characteristics of these subsystems are listed in Table 2.2.1. These characteristics are selected during the radar design process to meet the system specifications. The relationships between the characteristics and system performance parameters are listed in Table 2.2.2.

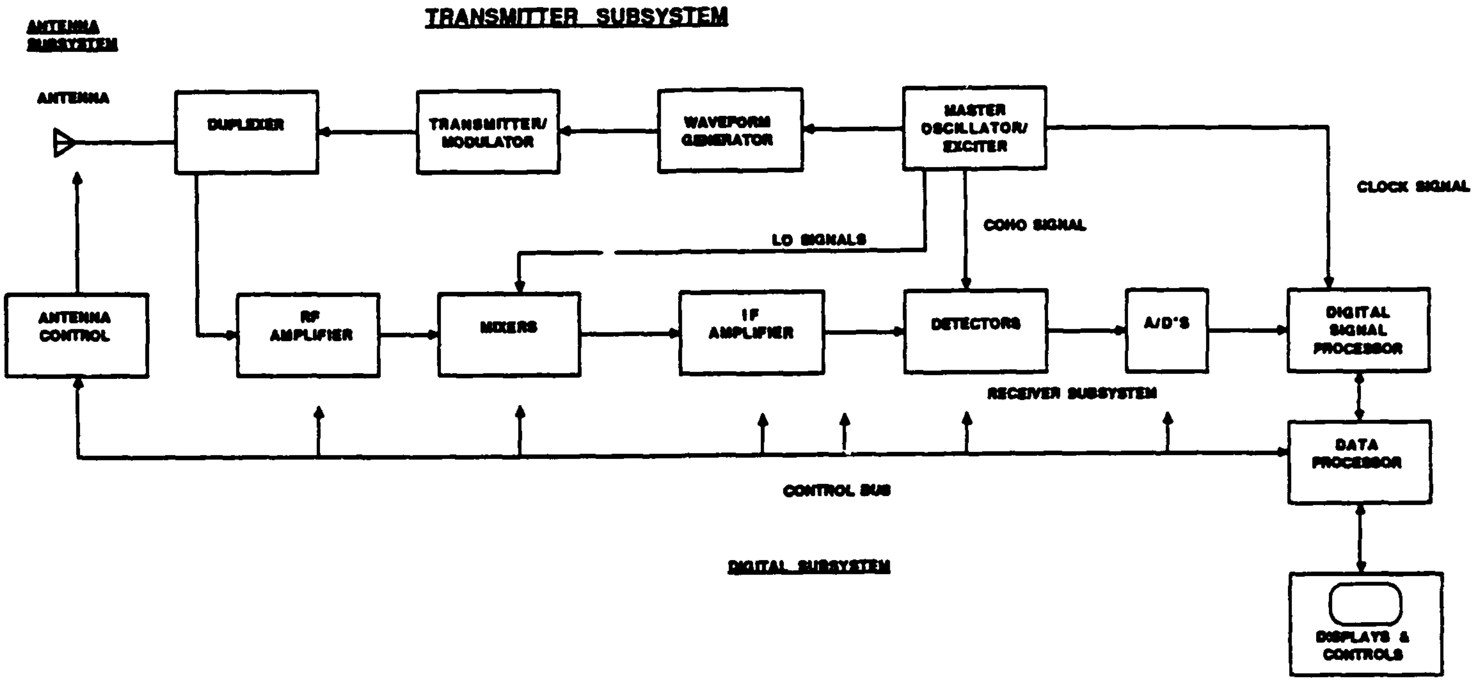


FIGURE 2.2.1 Typical Coherent Radar Block Diagram

TABLE 2.2.1 Radar Systems Characteristics		
	Frequencies (or wavelengths) of Operation	
	Antenna:	Type Dimensions (width, height) Beamwidths (az., el.) Scan coverage Scan rates Gain Polarization Sidelobes
	Transmitter:	Type Peak power Average power Bandwidth (tuneable) Waveform (PRF, pulsewidth, coding) Stability and noise sidebands EMI
	Receiver:	Type Number of channels Noise factor Bandwidth (instantaneous) Linearity Tuneability
	Signal Processor:	Type Functions Improvement factor Visibility factor Dynamic range (# bits, etc.) Dwell times Coherent bandwidths Noncoherent integration ECCM
	Radar Control and Data Processing	Type Modes Software
	Display and output data	Type of displays Data format

TABLE 2.2.2

RADAR SYSTEM CHARACTERISTICS	DETECTION RANGE AND COVERAGE	SUBCLUTTER VISIBILITY	VELOCITY RESPONSE	TARGET ACQUISITION TIME	SIMULTANEOUS TARGET CAPABILITY	RESOLUTION IN 4 COORDINATES	ACCURACY IN 4 COORDINATES	ELECTROMAGNETIC COMPATABILITY	VULNERABILITY TO ECM	TARGET DISCRIM. CAPABILITY
	RADAR PERFORMANCE PARAMETERS									
OPERATING FREQUENCY BAND	X		X							X
ANTENNA										
BEAMWIDTH				X	X	X	X		X	
SCAN COVERAGE				X						
SCAN RATES				X	X					
GAIN	X									
SIDELOBES		X							X	
TRANSMITTER										
AVERAGE POWER	X									
WAVEFORM			X				X			X
NOISE, STABILITY		X								
EMI								X		
RECEIVER										
TYPE								X	X	
NOISE FACTOR	X								X	
INSTANTANEOUS B.W.						X			X	X
LINEARITY		X						X	X	
TUNABILITY								X	X	
SIGNAL PROCESSOR										
IMPROVEMENT FACTOR		X								
VISIBILITY FACTOR	X	X								
DYNAMIC RANGE		X							X	X
DWELL TIMES	X	X		X	X					
COHERENT B.W.	X	X		X		X	X		X	X
NON-COHERENT INTEG.	X	X								
ECCM	X							X	X	
RADAR CONTROL & D.P.										
MODES				X	X				X	
SOFTWARE	X			X	X		X			
DISPLAY & OUTPUT DATA										
DISPLAY TYPE	X					X			X	X
DATA FORMAT										

A number of system performance parameters are determined entirely by the receiver and processor subsystems. Others, which may be difficult to evaluate by field testing procedures are primarily determined by these subsystems. Evaluation of these parameters is often most practical through closed-loop testing, by injection of controlled signals into the receiver and evaluating the output responses.

2.2.2 Receiver Subsystem

The radar receiver, shown in Figure 2.2.2, is a multistage amplifier and frequency converter. It accepts radio-frequency (RF) signals (along with noise and other interference) from the antenna, via the duplexer, amplifies and filters them, and presents them to the Signal Processor at a voltage level appropriate for analog or digital processing to extract target data.

The RF filter is often designed as a fixed network which passes all received frequencies within the tuning band of the system (e.g., 10% bandwidth). Its purpose is to reject out-of-band interference while introducing minimum loss to signals. The filter output may go directly to the mixer, although the trend in modern systems is to include a low noise RF amplifier, to reduce the noise contribution of the mixer. After preamplification at intermediate frequency (IF), an IF bandpass filter rejects noise and interference components lying outside the spectrum of the transmitted signal. Further IF amplification is provided to drive any IF analog processing that may be used: pulse compression using dispersive networks or delay lines, MTI or doppler filtering, gain control, etc. The IF output is often down converted by a second local oscillator to baseband, using in-phase (I) and quadrature (Q) detectors, prior to analog-to-digital conversion for further digital processing. In some modern systems, the conversion to digital form occurs immediately after IF bandpass filtering and gain control, permitting pulse compression, MTI and doppler filtering to be performed in the digital Signal Processor to be described below.

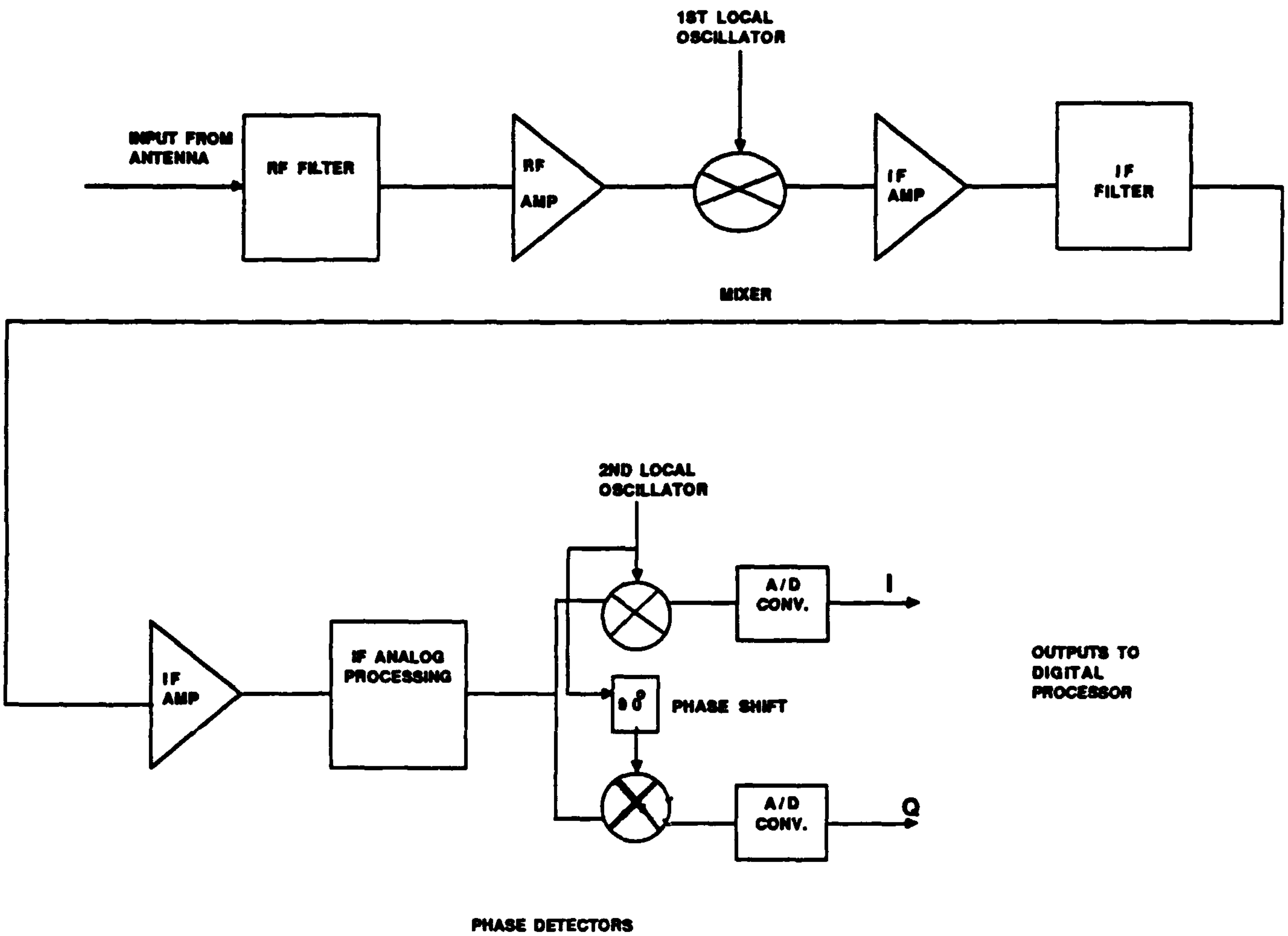


Figure 2.2.2 Typical Radar Receiver

2.2.3 Digital Subsystem - A General Description

Most modern radar systems make extensive use of digital hardware and software to provide overall control of the radar, as well as to provide signal and data processing functions. This digital subsystem provides a convenient interface for the control and execution of various types of closed-loop testing, since it is instrumented to exert control over the other subsystems that constitute the radar system.A general description of the organization of functions in the digital subsystem in modern radar systems is presented in the following subsection. This will support the later discussion of the manner in which closed-loop testing can be accomplished utilizing the digital subsystem as the test control interface.

The Digital Subsystem in modern radar systems may provide the following functions:

- Antenna beam steering and control
- Radar signal processing
- Radar data processing
- Radar control

Two classes of process are typically utilized in the organization of the Digital Subsystem. Signal processing oriented architectures such as data flow, systolic array or pipeline designs are well suited to the high throughput, repetitive processes such as beamforming, clutter filtering, doppler processing and other signal processing functions. A more general purpose architecture is better suited to provide the functions of radar control, radar detection post-processing and report formatting. Within the class of high throughput repetitive processing, a further distinction can be made between (a) beamforming, which is a dedicated, single function process, and (b) signal processing, which requires the use of a number of algorithms to support the various radar modes.

These considerations lead to a partitioning of the Digital Subsystem as shown in Figure 2.2.3. Each of the functional units is discussed in further detail in the following paragraphs.

'.2.3.1 Antenna Beamsteering Unit

The Beamsteering Unit provides for the computation of the phase shifter commands for all elements in the phased array antenna, based on steering direction and radiated frequency commands received from the Radar Control Unit. These computations must be repeated for each change in steering direction and frequency. The phase shifter commands are transmitted in to the individual elements, where they are acted upon by the phase shifters at these locations.

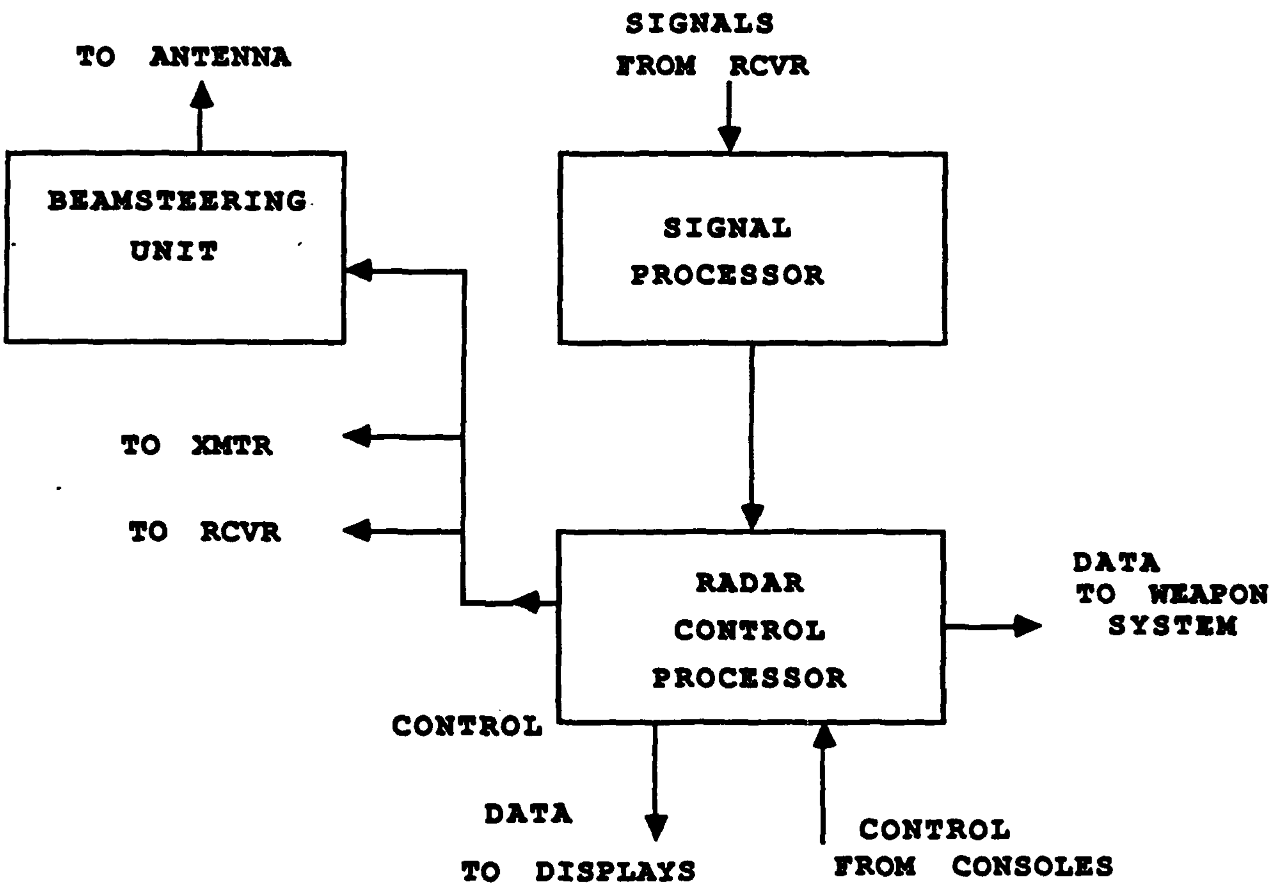


Figure 2.2.3 Digital Subsystem

The fundamental equation for computing the phase shift command for a given antenna element in the array is

$$\phi = \bar{z} \cdot \bar{u}/\lambda$$

where $\bar{z}$ = vector location of the element in the array,
$\bar{u}$ = unit vector along the desired antenna steering direction
λ = radiated wavelength.

The result of this computation is a phase shift command in units of cycles of phase shift. The integer part of the result is discarded, since it represents redundant cycles of additional phase shift. The fractional part is truncated to a small number of bits (typically 4 to 6 bits depending on the desired sidelobe level for the antenna beam), and sent to the phase shifter module in the array.

Since the array elements are typically located on a uniformly spaced rectangular or triangular grid, it is usually possible to take advantage of symmetries to reduce the computational load. One efficient beam steering algorithm computes two basic quantities for a given beam steering direction and radar frequency, i.e., the required incremental phase shift between two adjacent rows of elements in the array, and that between two adjacent columns in the array. Thus for a given beam steering command cx, cy and radar wavelength (λ) compute

$$a = dx \cdot cx/\lambda$$

$$b = dy \cdot cy/\lambda$$

Here dx and dy are the inter-element spacings between rows and columns respectively, and cx and cy are the direction cosiness of the beam pointing direction relative to the array coordinate grid. These two quantities are then incremented to provide the phase shift command for each element in the array,

$$\varphi_{o,o} = 0$$

$$\varphi_{m+1,o} = \varphi_{sub\, m,o} + a$$

$$\varphi_{m,n+1} = \varphi_{m,n} + b$$

A typical weapon locator radar may have approximately 4000 radiating elements in its antenna array. The required beam steering agility is typically to provide a new beam position for each radar dwell period, which may be on the order of 25ms. Thus phase shift

commands would be required at a rate of 160,000 per second. By using efficient algorithms such as the one outlined above the actual computational load to accomplish this beam steering agility can be reduced significantly.

2.2.3.2 Radar Signal Processor

The Signal Processor performs all of the high throughput processing functions on the received radar signals. Functions included are:

- Analog-to-digital conversion
- Pulse compression
- Clutter filtering
- doppler processing
- Signal detection (CFAR)

A frequent requirement is for flexibility in the use of various algorithms in these processes. Thus it is often necessary to instrument differing amounts of pulse compression, and to provide adjustable clutter notch filtering, variable coherent dwell times, etc. The Signal Processor must therefore be to some extent programmable.

A typical architecture, based on the "data flow" concept, is shown in Figure 2.2.4. Several processing elements (PE's) and memory modules (MEM's) are linked together through an interconnection network. Some of the PE's may be dedicated single-function units, such as an FFT processor or a transversal filter unit. Others may be more general purpose pipeline processor structures. Control and resource allocation is directed by the control processor.

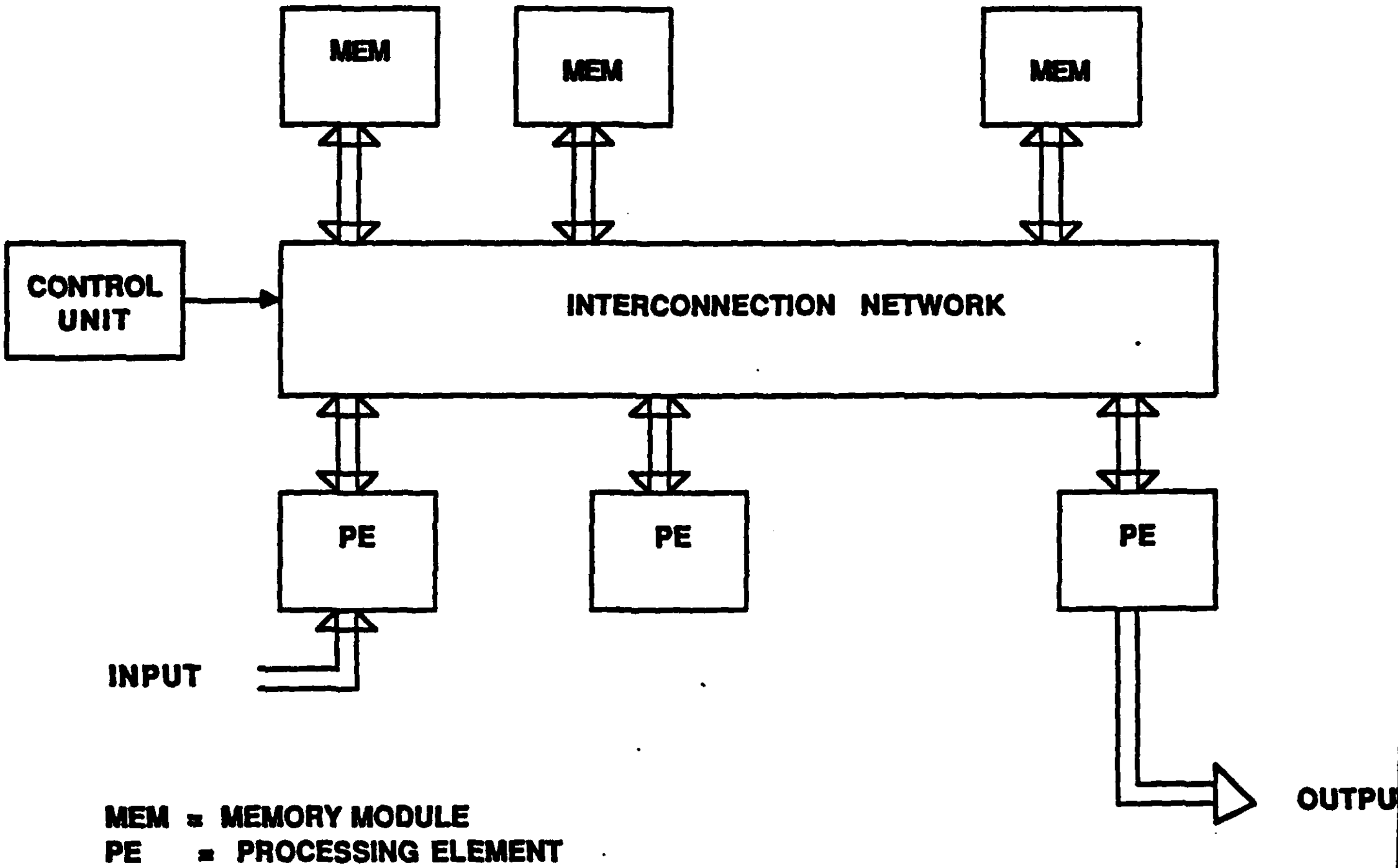


Figure 2.2.4 Radar Signal Processor Architecture

In a radar that provides monopulse tracking capabilities there are three channels of radar signals to be processed coming from the receiving subsystem: the monopulse sum channel and the two monopulse difference channels. Coherent processing of these signals requires that both the in-phase and the quadrature coherent video components of each channel be provided to the signal processor. Thus the analog to digital (A/D) conversion consists typically of six separate convertors. The required accuracy of the conversion is typically 8 to 10 bits per sample. The sample rate for each convertor is set by the radar signal bandwidth, which in the case of a weapon locator radar may be on the order of 2 MHz.

Pulse compression can be accomplished either in the receiving subsystem in analog form, or in the digital subsystem in digital form. If it is to be accomplished in the digital subsystem, the computational process is typically one of a sliding window transversal filter that instruments a linear function (a weighted combination) of the adjacent signal samples within the window.

Clutter filtering is included to provide for rejection of nonmoving or slow moving clutter, and to provide moving target indication (MTI). It typically consists of computing weighted combinations of corresponding range samples from a small number (two to four) of successive pulse repetition intervals. Buffering of the range samples from one or more successive repetition intervals is therefore required.

Target velocity measurement (as well as clutter rejection) is provided by instrumenting a set of doppler filters. This is typically accomplished by an FFT algorithm that generates a set of contigous filters that span the complete unambiguous doppler interval (equal to the radar pulse repetition frequency). During each coherent radar dwell period these samples are processed, one range at a time, in an FFT process that results in separating the returns from a given range into a set of doppler bins.

The range samples arrive at the Signal Processor in range sequence following each transmitted pulse. The doppler filter processing requires that all samples received from a given range during the coherent dwell period be processed together. Thus a memory organization that provides efficient two-dimensional "corner turning" is desired. The successive range samples are stored in the two-dimensional structure as successive horizontal vectors, and then read out as successive vertical vectors. During the data storage time the read-in sequence is as follows: All range samples from the first pulse interval, followed by all range samples from the next interval, etc. During the data retrieval time the read-out sequence is all samples received during the dwell from the first range gate, followed by all samples from the second range gate, etc. The actual FFT computation is accomplished by repeated application of a basic multiply and add function to appropriately selected pairs of data samples.

Target detection consists of reporting out to the Radar Control Processor those cells that exceed a threshold. It is usually required that some CFAR (constant false alarm rate) control be included. One method of providing this function consists of varying the detection threshold for each resolution cell, based on an analysis (averaging, for example) of the signal strengths in a number of surrounding resolution cells.

Frequency agility is often included in the design of the radar in order to provide ECCM advantages, to provide for resolution of range ambiguities, etc. The Radar Control Processor generates the sequences of frequencies to be used by the system.

All antenna steering commands are generated by the Radar Control Processor and provided to the beam steering unit for translation into detailed phase shifter commands for the array antenna. The basic search pattern scanning routines for the antenna are generated in this unit. The angular coordinates of initial target detections are utilized in generating antenna pointing commands for reconfirmation dwells. The pointing commands for tracking are also generated here.

An important function is the control of system and subsystem testing. It is typical to provide for automatic sequencing of system health checks under the control of the Radar Control Processor. This often takes the form of the execution of a set of diagnostic routines that issue commands to the various subsystems and monitor the results that are fed back to the Radar Control Processor. These processes are executed in an interleaved manner with the normal operations of the radar system.

The radar data processing functions include:

- Monopulse angle estimation
- Range ambiguity resolution
- Dwell-to-dwell correlation

2.2.3.3 Radar Control Processor

The Radar Control Processor provides for the overall control of the radar system. It also processes and interprets the output data from the radar signal processor.

Since the functions to be performed by this portion of the Digital Subsystem do not require a high throughput rate, they are typically instrumented with general purpose

computer architecture. Multi-function interrupt driven processing is typical, with housekeeping tasks being relegated to the background, or postponed, when higher priority functions are required to be performed.

The radar control functions include:

- Radar mode timing and control
- Frequency agility
- Antenna steering command generation
- Built-in-test (BIT) control

Typically the overall timing control for the radar system is provided by this unit. This includes the generation and distribution of all synchronization timing for the transmitter, receiver and signal processor. The radar operating modes, i.e., target search, target confirmation, target track, clutter mapping, etc., must be interleaved adaptively according to the requirements of the following:

- Multiple scan target association
- Target tracking
- Weapon launch site estimation (weapon locator radar)
- Target reporting and display

These functions all involve processing of data received from the Signal Processor, and are of a more general computational form.

2.3 System Test Planning

Before a radar system design or model is evaluated, the requirements for its modes of operation and its performance in these modes must be known, so that the evaluation can be made with respect to these requirements. This means that a system-level specification must be available, describing the functions to be performed by the radar, the regions over which these functions are to be performed, the targets to be detected, measured, or identified, and the background environment in which this is to take place.

Evaluations are normally made in several steps, depending on the status of the radar program and the resources available to the evaluator:

Analysis and simulation
Field test
Extrapolation from field test, using both analysis and simulation.

2.3.1 Statement of Requirements

For each type of evaluation, a different statement of radar system requirements may be necessary. In the analysis phase, for example, the target cross section is specified by its mean value in square meters, with a fluctuation model usually from the Swerling cases. Atmospheric conditions will be calculated from models and used to adjust the signal strength in the simulator. In field tests, a specific aircraft is used, its cross section (possibly augmented) having been measured in advance to relate it to the radar specification requirements. Weather conditions are observed by standard meteorological instruments, with rainfall estimated over the radar-target path. Extrapolation to other targets is done by scaling to their physical sizes or by using measurements from a cross-section range. Extrapolation to other weather environments relies on models or direct measurement of attenuation on communication circuits or radars similar to the radar under evaluation.

The difficulty in this evaluation process is that the specification, against which the radar system may have been proposed or developed, may have stated the requirements in only one way (e.g., detect a 1.0 m^2 aircraft target (Swerling Case 1), flying at one km altitude in 4 mm/h rain, with 0.9 single-scan probability of detection at a range of 100 km. The procedures for analysis and simulation in this case are well defined, but the translation to a specific test target and the establishment of the rainfall rate under test conditions are more difficult. The evaluator must be able to translate the numerical specifications to the actual target and environment, and back again, if the field evaluation is to be meaningful.

The following system performance parameters are to be evaluated by the system level testing:

a. Detection range and coverage
b. Subclutter visibility and velocity response
c. Target acquisition time
d. Number of targets handled simultaneously
e. Resolution in four radar coordinates (angles, range, radial velocity)
f. Accuracy in four radar coordinates and in output coordinates
g. Electromagnetic compatibility
h. Vulnerability to ECM
i. Target discrimination capability

The flow of the radar system design process and system-level testing is illustrated in Figure 2.3.1. In order to define the tests to be performed, to evaluate the accuracy of their results, and to interpret these results in terms of radar subsystem characteristics, it has been determined that the following approach is required, for each generic system and each system parameter.

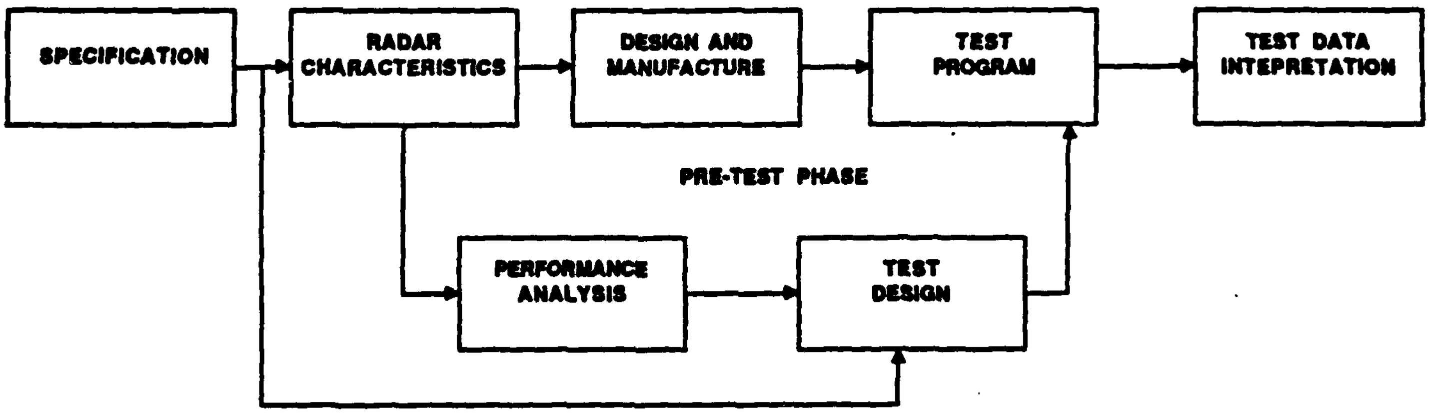


FIGURE 2.3.1 FLOW OF RADAR SYSTEM DESIGN AND SYSTEM-LEVEL TESTING PROGRAM

The basic purpose of the test program is to relate the actual performance of the radar to the requirements imposed by the specification. These requirements may either be spelled out explicitly in the specification, or they may be derived from over-all performance requirements or goals. The first step in the process, before test procedures are prepared, will be to establish the requirements for items (a)-(i) listed above, and the basis for each requirement: Specification paragraph or method of derivation from the specification.

2.3.2 Evaluation by Analysis

In the early stages of a radar development or procurement program, the hardware is not available for test, and evaluation must be made on paper, using analytical techniques. The necessary analyses may start from fundamental theoretical models of radar performance, or from available test data on similar radar equipment which may be adapted or improved to meet the new requirement. Some areas of radar performance are well understood, so that accurate calculations of system performance can be made from known radar parameters and models of the external environment in which the radar is intended to operate. In other areas, theoretical procedures have not been developed to the extent necessary for accurate prediction of radar performance, and simulation or field test will be required. Even in areas where adequate theory exists, there remains considerable uncertainty as to the validity of the models used to represent targets and environmental effects, and key aspects of performance must be validated by test. A thorough analytical evaluation is required, however, to identify the critical areas in which tests are most necessary to resolve uncertainties.

The need for analytical evaluation prior to testing is based on the limited test resources available, and the statistical nature of most radar performance measures. If the test resources are spread over the entire range of conditions in which the radar is expected to operate, there is little chance that the number of data points in any one region will be adequate to arrive at statistically valid conclusions. Analysis, if properly carried out, can identify the most critical regions, in which the radar design is marginal or the analytical models are weak, as well as broad regions in which satisfactory performance can be expected with high confidence. A relatively few tests in these regions, repeated to give valid statistical measures of performance, can serve to validate or correct the analytical and simulation models near their boundaries of uncertainty, and give confidence to their use in extrapolation to other cases. The purpose of testing is to resolve uncertainties. Little new information is obtained when the tests merely confirm things that are already known with high confidence.

An example shown in Figure 2.3.2, in which the desired system parameter (e.g. detection probability, acquisition time, or target discrimination probability) is plotted as a function of target range. Through analysis, the range region in which the system performance parameter changes rapidly can be identified, and the test plan can be written to explore this area thoroughly. In the figure, it can be seen that testing in the vicinity of R_{50} is most likely to be productive and to validate the radar system design with minimum resources. Once the curve in this area is validated, extrapolation to higher and lower levels of performance can be carried out with little uncertainty. If desired, three series of tests can be carried out, covering the upper knee and the lower knee of the curve as well as the steep slope near the center. It must be recognized, however, that the number of tests necessary to confirm probabilities near 99% or near 1% will be far higher than needed near 50%. Tests scattered over the entire curve, with few samples at each level, may be entirely inconclusive, giving no confidence at any level of radar system performance.

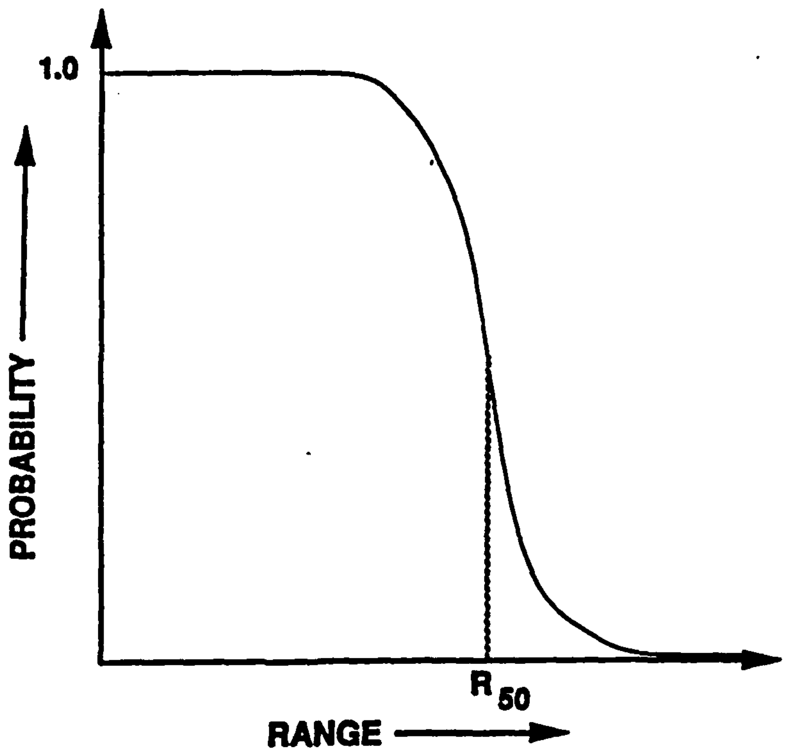


FIGURE 2.3.2

2.3.3 Evaluation by Simulation

In many areas of radar performance, the processes applied to the signals and the resulting output data are complex, involving nonlinear operations and logical paths which may not lend themselves to any reasonable mathematical analysis. While simplified models can be created to obtain approximate analytical results, simulation may be the only way to predict the actual performance of these processes with multiple inputs from targets and interference. This is especially true in areas such as target identification and multiple-target tracking. Again, however, it is important to perform as thorough an analysis as possible to guide the choice of parameters for simulation and to help interpret the results.

2.3.4 Determination of Test Conditions

The techniques of analysis and simulation are seldom reliable enough to permit favorable decisions on production of radars to be made without validation by actual field test. On the other hand, designs which have fundamental flaws or limitations can often be rejected on the basis of analysis alone. Given particular areas of concern, identified by analysis or simulation, it will usually be possible to design test programs to determine whether these areas are adequately addressed by the radar design. The key to a successful test program is to reduce the number of test variables so that the test data will be definitive *enough, in the statistical sense*, to resolve the initial uncertainties.

In general, field test conditions are difficult to determine and describe accurately, especially those related to clutter and propagation effects. Given the limited resources usually available for testing, it is preferable to perform repeated tests under a few well defined conditions which will permit adequate statistical validation of system performance for those conditions, than to spread the test resources over all possible combinations of operating conditions and end up with too little data and questionable results in each area. It is then possible to use analytical models to extrapolate performance to conditions not too distant from those covered by test data.

2.3.5 Test Design

After suitable analysis, tests may be designed to measure each system performance parameter. The test design consists of specifying such factors as the following:

a. Target type, size, velocity, flight path
b. Radar location, mode, waveform, scan procedure
c. Environment: weather, ECM, clutter (determined by location)
d. Presence of multiple targets, real or simulated
e. Types of data to be recorded

The test design is not carried out to the level of step-by-step procedure, but rather as a description of the test objectives, general methods to be used, and conditions of the radar and its environment.

2.3.6 Test Procedure

The detailed, step-by-step procedure to be followed during the test can now be prepared on the basis of the test design.

2.3.7 Recorded Data

The details of data to be recorded, its format, and how the start and stop times of each batch of data are to be determined can now be specified.

2.3.8 Evaluation

The methods of evaluating the data should be determined and specified during the preparation of the test plan and procedure. An example of this process would be to specify that target position data from the radar under test will be reduced to Cartesian coordinates, compared with range instrumentation radar data (e.g., AN/FPS-16), and differences calculated. The mean and standard deviations of the differences would be the output. If the desired data are errors in radar spherical coordinates, the AN/FPS-16 data would be converted to spherical coordinates at the test radar, differences obtained, and the mean and standard deviations of those differences would be the outputs.

2.3.9 Interpretation

The final step in the system test process is the interpretation of the test results in terms of subsystem parameters: such characteristics as transmitter power, receiver noise factor, or antenna gain and pattern. This interpretation can lead to decisions as to the next lower level of radar testing: the detailed evaluation of subsystems, circuits and components to determine reasons for any departure of the radar system from its specified or expected performance. It can also lead to discovery of defects in the test procedure or environment of the test, as a guide to retesting under more accurately controlled conditions.

2.4 Test Methodology and Procedures - Closed-Loop and Field Testing

Test procedures have been identified for use in evaluating system level performance for each of the system parameters given in Section 2. These procedures are listed in Table 2.4.1, together with their classification as either closed-loop (C-L) or field tests (F) and recommendations as preferred (P) or alternate (A) approaches. These procedures are described in detail in Section 2.5.3 and 2.6, together with the rationale for choosing preferred and alternate approaches.

TABLE 2.4.1			
System Test Procedures			
Test Number and Description	Type	Preferred (P) or Alternate (A)	Report Section
1.0 Detection Range and Coverage			
1.1 Live target/calibrated reflector	Field (F)	P	2.6.1
2.0 Subclutter Visibility (SCV) and Velocity Response			
2.1 Strong (live) clutter + phase modulation at IF (SCV)	F	P	2.6.2
2.2 Strong (live) clutter + RF or IF injection of moving target (SCV)	F	A	2.6.2
(Repeat above with chaff and/or rain)	C-L	P	2.5.3.1
2.3 IF or video injection of simulated, moving target (velocity response)			
3.0 Target Acquisition Time			
3.1 Simulated target, injected at IF or video	C-L	P	2.5.3.2
3.2 Live target	F	A	2.6.3
4.0 Number of targets handled simultaneously			
4.1 Simulated targets injected at IF or video	C-L	P	2.5.3.3
5.0 Resolution in Four Radar Coordinates			
5.1 Measure received pulse characteristics within DSP for strong (real) point target return (range)	F	P	2.6.4
5.2 Inject train of pulses into receiver and processor (doppler)	C-L	P	2.5.3.5
5.3 Inject waveform generator output into receiver (range)	C-L	A	2.5.3.8
5.4 Measure cardinal plane antenna patterns, for various scan angles if phased array (angle resolution)	C-L	P	2.5.3.6

TABLE 2.4.1 *SYSTEM TEST PROCEDURES*			
6.0 Accuracy in Four Radar Coordinates and in Output Coordinates			
6.1 Boresight tower (angles)	F	P	2.6.5
6.2 Track live targets - range + angles + tracker smoothing + prediction	F	P	2.6.6
7.0 EMC			
7.1 Measure transmitter output spectrum (EMI)	C-L	P	2.5.3.7
7.2 Measure spurious radiation from all subsystems in EMC facility (EMI)	C-L	P	2.5.3.7
7.3 Where special requirements exist, measure signal levels at IF and at the output with far-field sources of high power at operating band frequencies and other frequencies of concern	F	P	2.6.7
8.0 Vulnerability to ECM			
8.1 ECM simulator in near field (ECM susceptibility and LPI capabilities)	F	P	2.6.8
8.2 ECM sources in far field (sidelobe cancellation)	F	A	2.6.8
8.3 ECM simulator direct coupled and simulated target (ECM susceptibility)	C-L	P	2.5.3.9
8.4 ECM simulator for determining arm susceptibility	F/C-L	P	2.6.9
9.0 Target Discrimination			
9.1 Live target tests with various target types	F	P	2.6.10
9.2 Simulated or recorded targets injected at IF or video	C-L	A	2.5.3.9
10.0 Airborne Radar - Special Requirements			
10.1 SCV - ground test (roof-top) + airborne	F	P	2.6.11
10.2 Resolution - and accuracy into recording. "Dry Lake" + "Spoke" facility	F	P	2.6.11

2.5 Closed-Loop Testing Procedures

Closed-loop testing consists of injection of specific test signals into the receiver and digital subsystems and analyzing the responses obtained. A signal simulator generates signals representing target returns, clutter, ECM, etc. These are injected into the radar system under test. The radar system performance with respect to these signals is observed.

2.5.1 Computer-Aided Testing

This closed-loop testing of the radar system involves a set of tasks that are ideally suited to Computer-Aided Testing (CAT), which is well suited to implementing a well defined set of repetitive tasks where timing, accuracy, and repeatability are important. The fact that modern radars operate under computer control and that significant portions of the receiver are digital processors makes the CAT approach the most appropriate for this type of system level testing. However, it should be recognized that access points at inputs and outputs of the subsystems must be provided.

2.5.2 Waveform Simulation

In using the (CAT) Computer Aided Testing approach to closed-loop testing it is required that receiver input waveforms be simulated and that specific waveform characteristics can be related to realistic target threat situations. The threat model defines the number of targets and, for each target, provides a waveform sequence with parametric variations (appropriate sum and difference channel amplitude, phase and frequency) that corresponds to the trajectory of that particular target in the threat model. Threat models can be constructed to cover the entire operating environment of the radar. The CAT computer can be programmed to record and display a wide array of subsystem data as well as system level mission results. Since the CAT computer established the threat it is a straightforward matter to display and score the resulting radar report. The threat model should include the ability to incorporate both clutter and ECM waveforms with the ability to vary these inputs to cover the expected range of battlefield conditions. The CAT computer should be capable of varying the key receiver parameters over a range of values that is commensurate with the realistic variation to be expected as a function of environmental conditions.

The general test approach is diagrammed in Figure 2.5.1. Simulated signals are injected into the receiver and digital subsystems. The performance of the radar is determined through monitoring of the digital subsystem outputs. The tests are controlled and managed by means of a Test Control Computer (TCC) which typically would be a small

PC-type desk top computer with the usual peripherals. The test computer is programmed to control both the simulated signal generator and the radar under test through programs written for each specific test to be conducted.

The Test Control Computer inserts test scenario data into the radar system and extracts performance data from it by means of a direct memory access (DMA) interface with the Radar Control Processor. Interrupt signals from the TCC can control the sequencing of the radar system functions. By this means the radar system operation can be halted to allow examination or modification of data in memory, mode changes can be forced to take place, and target returns and track histories can be inserted or removed.

The TCC also exerts control over the test signal simulator equipment. The timing and sequencing of target returns is defined in order to simulate target returns at desired ranges and angular coordinates. Detailed signal parameters such as pulsewidth, pulse shape, doppler frequency, etc., are also established by this computer.

Console keyboards, displays and recording equipment associated with the TCC provide for overall test control and documentation. Thus, a completely flexible method of control of the system testing can be achieved.

A possible nucleus of equipment around which the above described closed-loop testing set-up can be constructed is the Model HP-8770S Signal Simulator System of Hewlett Packard [2]. This equipment consists of a waveform synthesizer and a micro-computer, along with waveform simulation software. The synthesizer has the capability to synthesize complex IF and video signals for multiple targets, along with added clutter and noise, all under computer control. The waveform simulation software utilizes a higher level language for ease of use. Resulting waveforms can be stored on disk for later use, or inserted directly into the synthesizer for immediate use.

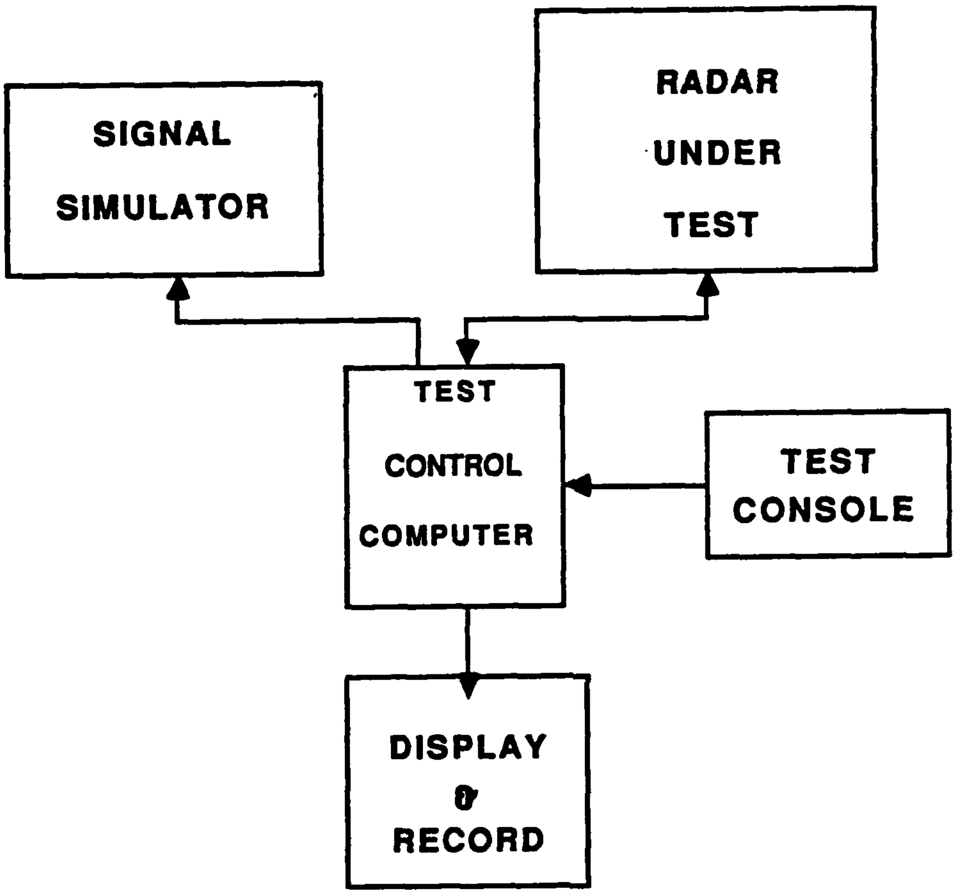


FIGURE 2.5.1 CLOSED-LOOP TESTING BY COMPUTER CONTROL

2.5.3 Procedures

Specific system level parameters that are best evaluated using closed-loop testing include:

a. Velocity response (Test 2.3)

b. Target acquisition time (Test 3.1)

c. Simultaneous target handling capacity (Test 4.1)

d. Doppler resolution (Test 5.2)

e. Angular resolution (Test 5.4)

A discussion of each of these system performance parameters and the method of evaluating each using the above described closed-loop testing procedures will be outlined in the following paragraphs:

2.5.3.1 Velocity Response (Test 2.3)

The velocity response of a radar is represented by a plot of the [3.p.239] relative target output signal level as a function of target radial velocity (as measured by the doppler frequency of the target). Typical velocity response curves are shown in Figure 2.5.2, representing a radar with a fixed PRF and a signal processor filter characteristic of a double-delay MTI canceller with various degrees of feedback. The relationship between the doppler frequency, f_d and the radial velocity v_t of the target is given by

$$f_d = \frac{2v_t}{\lambda}$$

For a radar having a single PRF, the velocity that gives a doppler frequency equal to the PRF f_r is the first blind speed. And the velocity corresponding to a doppler frequency of $\frac{f_r}{2}$ is known as the "optimum velocity".

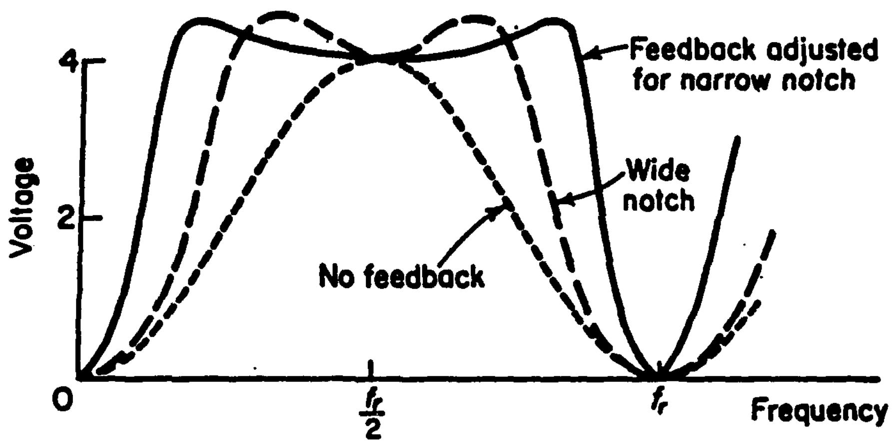


FIGURE 2.5.2 DOUBLE DELAY MTI CANCELLER VELOCITY RESPONSE CURVES FOR VARIOUS DEGREES OF FEEDBACK (f_r = REPETITION FREQUENCY)

The velocity response of a given radar design is determined by the PRF values, the wavelength and the filtering characteristics of the signal processor. Multiple PRFs (or staggered repetition periods) are frequently used to eliminate blind speeds within the target velocity region of interest. Complex filter characteristics (typically MTI plus coherent doppler filtering with FFT algorithms) are employed to achieve the desired rejection of the various types of clutter (e.g., ground clutter, weather clutter, chaff, and birds). Performance with respect to clutter of various types is most accurately determined at the system level by field measurement of subclutter visibility (SCV) (see 2.6.2).

The velocity response could conceivably be measured by flying live targets with known radar cross sections toward the radar at all (achievable) velocities of interest, but this would be a very inefficient use of resources. Closed-loop measurements can completely characterize the relative velocity response function. A small number of field measurements of SCV and detection range can be used to calibrate the velocity response curves.

The technique for measuring the velocity response of the radar system utilizing the computer assisted testing set-up shown in Fig. 2.5.1 is as follows. The signal simulator generates target echo pulses with varying amounts of doppler shift. These pulses are triggered by the timing signals generated in the Radar Control Processor, so they represent properly any staggered PRF scheme utilized by the radar. The pulses can be injected into the radar under test either at the IF or the video portion of the receiver. The velocity response is obtained by monitoring the output of the signal processor where the doppler filtering is accomplished.

2.5.3.2 Target Acquisition Time (Test 3.1)

Target acquisition time limits in modern radars are determined by signal processor filtering and signal integration delays, plus the delays resulting from data processing functions associated with detection, target reporting, classification, track initiation, etc. Since target tracking is not typically effected with electro-mechanical servos, but in a mode of operation with an electronically scanned array antenna, the delay times associated with antenna beam steering are negligible compared with the above signal and data processing delays. Track-while-scan systems introduce delays associated with the scan rates and coverage volumes (or revisit times), with the remaining factors influencing acquisition time being the above signal and data processor delays. Thus, target acquisition times are best measured on a closed-loop basis, involving only the digital subsystem.

Measurement of target acquisition time with the computer assisted testing configuration of Fig. 2.5.1 is as follows. The signal simulator generates a train of pulses representing the radar returns from a target. These pulses are injected into the IF or video

portion of the receiver, or directly into the signal processor in digital form. The test computer causes the radar system to proceed through the normal operational steps of signal filtering, detection, post-detection integration, target verification, classification, etc.., and track initiation. The effects of scan coverage procedures and revisit times are included through coordinated control by the test control computer of the pulse train timing of the signal simulator and of the mode sequencing of the radar control computer. The progress of the simulated target signals through the various steps leading to acquisition is monitored and reported by the test control computer.

2.5.3.3 Simultaneous Target Handling Capacity (Test 4.1)

The number of resolvable targets that can be handled simultaneously by a given radar is determined partly by signal processor delays and, more particularly, by the speed and memory capacity of the data processor for performing its functions of target reporting, target verification and classification, track initiation, track continuation, etc. The limitations imposed by the switching of electronically scanned antenna beams from target to target are determined by the dwell time requirements (integration delays) and the data processor scheduling function, rather than the antenna beam switching times (which are typically measured in microseconds). Thus, closed-loop tests involving the digital subsystem will suffice to evaluate the system-level capabilities for target handling.

Closed-loop evaluation of this target handling capability is accomplished by programming the signal simulator to generate a number of simultaneous target returns at resolvable ranges and dopplers. These pulses would be injected digitally at the input to the digital subsystem. Separate tests would involve having all simultaneous targets within one antenna beam, or distributed throughout the scan volume. The test control computer would monitor the operation of the radar in filtering, detecting and tracking these targets. Additional new target returns could be added to determine the capability of the radar system to establish new track files when already occupied with maintaining existing tracks on previously detected targets.

2.5.3.4 Target Resolution

Target resolution in three of the four radar coordinates (doppler and two angles) is most efficiently accomplished by closed-loop testing, since controlling field tests with live targets spaced at barely resolvable separations is extremely difficult (measurement of range resolution is described as a field test in Section 2.6.4). The exceptions to this argument are mapping radars, including airborne synthetic aperture radars, where resolution and map quality are significantly affected by the accuracy achieved by the radar in compensating for non-ideal motion of the radar platform. In these cases radar maps of known

scenes (including test patterns of reflectors) must be acquired in field tests and subsequently analyzed to determine resolution and map quality. These latter cases are discussed in Section 2.6.11.

Figure 2.5.3 represents the general nature of radar output response function in a particular dimension (x). The 3-dB width of the function is given by the dimension A, and the peak sidelobe level is given by the dimension B. The dimension A is typically taken to be the primary measure of resolution, since this value is (approximately) the minimum spacing for which two equal magnitude target signals can be resolved. Resolving a small target signal in the presence of a large one puts the small target in competition with the skirts of the response function for the larger signal and requires greater spacing before resolution is achieved. In the limit, the sidelobe levels determine how small a target (in cross section) can be detected in the presence of a large target. When the ratio of the target signal levels is greater than the mainlobe to sidelobe ratio (dimension B), the smaller target cannot be detected in the sidelobe region of the larger target.

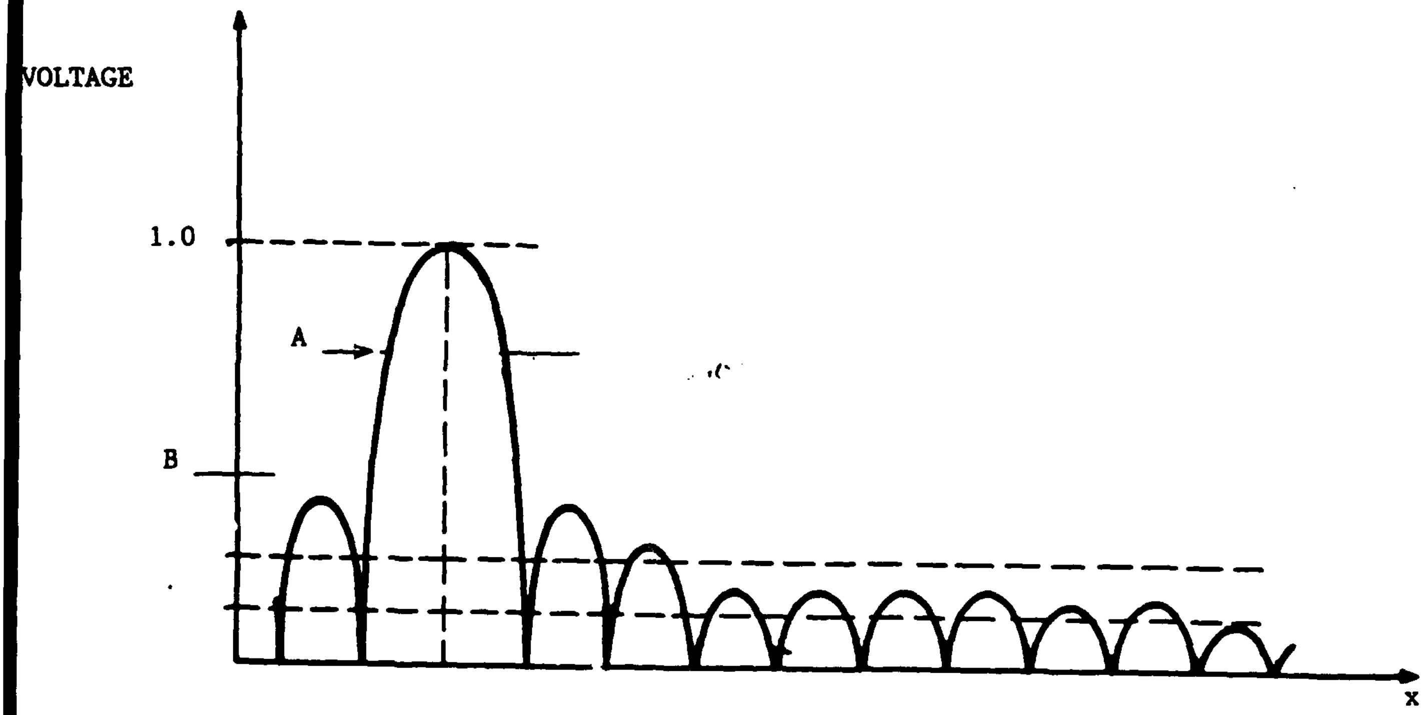


FIGURE 2.5.3 TYPICAL RESPONSE FUNCTION

In general, radar requirements focus on resolution of targets of equal or nearly equal sizes or signal strengths, although peak range sidelobes may be specified for pulse compression systems in order to accommodate small targets in the presence of large targets. Also, synthetic aperture mapping radars typically require low sidelobes in both the range and doppler frequency dimensions in order to map accurately areas of low reflectivity adjacent to areas of high reflectivity (i.e., land/water boundaries, etc.).

2.5.3.5 Doppler Resolution (Test 5.2)

In the doppler frequency dimension, A in Figure 2.5.3 is approximately equal to the coherent integration filter bandwidth, and the sidelobes result from the combined effects of the filter characteristics and the finite dwell time of the transmitted pulses.

The doppler response function can be directly evaluated using the closed-loop measurement set-up of Figure 2.5.1. The simulated target signal is injected at the input of the digital signal processor. The output of the signal processor is recorded as the doppler of the input signal is varied. A second type of test consists in applying simultaneously two signals closely spaced in doppler to the signal processor input, to verify that they are resolvable.

2.5.3.6 Angle Resolution (Test 5.3)

In the azimuth and elevation dimensions, the response function correspond to the antenna patterns in the two planes. Measurements of azimuth and elevation angle resolutions are recommended to be effected by antenna subsystem pattern measurements. These pattern measurements will also provide the data required to assess elevation coverage for search radars with shaped beams in elevation (typically csc^2 shaping), and ECM vulnerability through sidelobes.

Two methods for measuring antenna patterns are recommended. First the compact antenna range, soon to be delivered to Fort Huachuca, promises to be an excellent facility for such measurements. Although it is yet to be determined what the limitations in sidelobe level measurements will be for the compact range (as a result of spurious reflections or non-planar phase fronts in the quiet zone), the presently available data suggest that these limitations should be acceptable. (Capability to measure sidelobes down to -40 to - 50 dB in the microwave band is desired). The antenna sizes of interest (see Sections 2.7) are considerably smaller than the width of the quiet zone of the compact range, hence sidelobe measurement limitations for these antennas when located near the center of the quiet zone should be very low.

The ability of the compact range positioner to rotate the antenna under test offers an especially useful capability for pattern testing of electronically scanned antennas, since the real patterns for such antennas can be measured by electronically fixing the beam position relative to the array face and mechanically scanning the antenna. Without such a positioner, patterns could be obtained by electronically scanning relative to the source position, but these patterns are not the true spatial patterns that correspond to a particular beam position. The procedure for making such pattern measurements is the same as that which is prescribed by the compact range suppliers, with the patterns of primary interest being in the cardinal planes of azimuth and elevation.

An alternate approach to the compact range would be to implement a conventional far-field antenna range. Fort Huachuca appears to offer numerous possible sites for such a range, where unobstructed line-of-sight for distances of 350 meters or more is available, and bridges, towers and other objects are sufficiently far away to minimize reflections which can limit the depth of sidelobes that can be measured. An antenna range of this type would require a positioner similar to that used in the compact range in order to provide proper evaluation of electronically scanned antenna and even to permit pattern cuts at all angles with mechanically scanned antennas.

The general procedure for measuring antenna patterns in such a far-field range would involve the following steps:

1. Mount the test antenna on the positioner.

2. Rotate the positioner to establish the positioner scan plane to correspond to the plane of the desired pattern cut.

3. Rotate the polarizer at the signal source to correspond to the specified antenna polarization.

4. Run the pattern measurement program by rotating the positioner angle to scan the antenna beam past the direction of the signal source, and record the pattern.

Modern pattern test ranges (both compact and far-field types) are typically operated under complete computer control, including the scanning regimen and pattern plotting in various formats.

Detailed procedures for conducting antenna tests are presented in references [4] and [5].

2.5.3.7 Electromagnetic Compatibility (EMC)

Electromagnetic interference caused by the radar to be evaluated is of concern for a number of reasons, including: Interference with other radars of the same type operating within the same band but on different channels, interference with other RF systems such as other radar types, communications and data transmission systems, and possible concern about the radar being detected and located through spurious radiation. Evaluation of the radiated power levels within the radar operating band but outside the instantaneous transmission bandwidth of the radar under test can be accomplished with the transmitter subsystem alone, using facilities like the Blacktail site and operating the transmitter into a dummy load, as shown in Figure 2.5.4. Test procedures for these measurements are outlined in ITOP, 6-2-530 [6, para. 3.2].

Evaluation of the radiated power levels outside the radar operating band should be conducted with the transmitter feeding the antenna and the spectrum analyzer connected to a receiving antenna as shown in Figure 2.5.5. The antenna is included in these tests, because it acts as a filter to out-of-band signals. These measurements should be made in the frequency regions where sum and difference plus harmonic combinations of exciter internal frequencies can produce signals outside the radar band as well as at the second and possibly (depending on how high the fundamental frequency is) the third harmonic of the radar (fundamental) carrier frequency. The Blacktail facility would, again, be appropriate for these tests. The receiving antenna can be either in the near field or far field of the radar antenna beam.

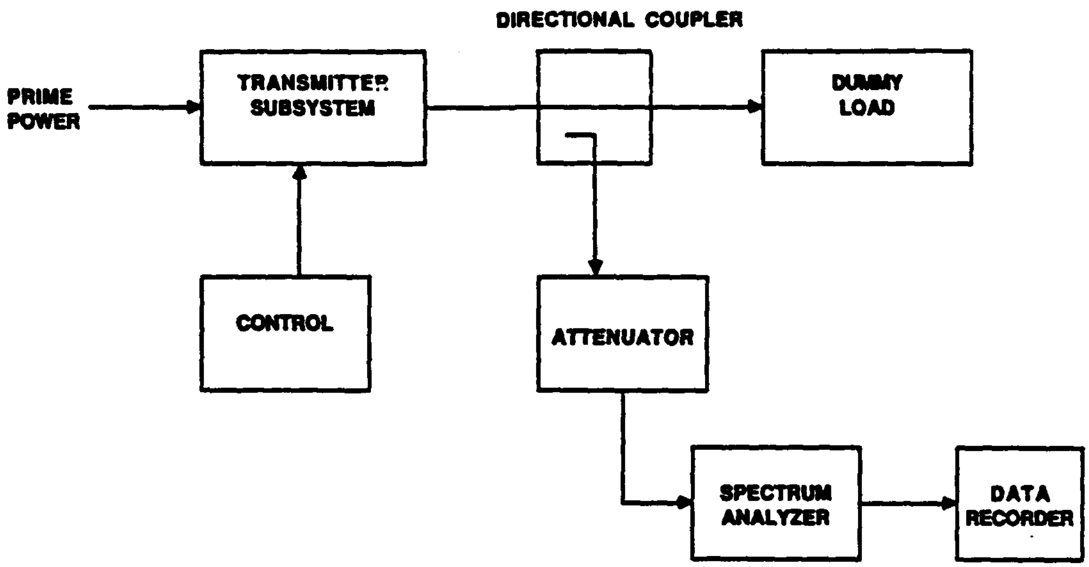


Figure 2.5.4 TRANSMITTER TEST FOR IN-BAND EMC

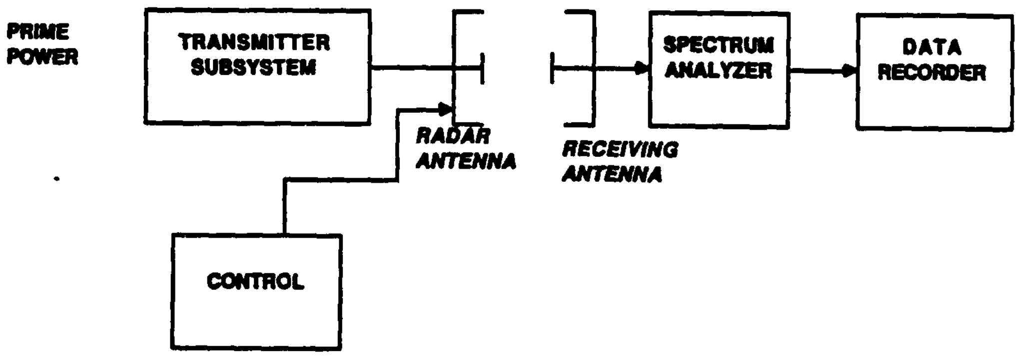


Figure 2.5.5 TRANSMITTER TEST FOR OUT-OF-BAND EMC

The two Test procedures outlined above represent test 7.1.

Spurious radiation from all subsystems would include radiation from the low frequency oscillator and counters in the exciter and waveform generator and from the digital subsystem. In addition, radiation (both in-band and out-of-band) at the frequencies of interest in the above paragraphs may be of concern where the radar transmitter can be turned off to avoid detection, location, and anti-radiation missile (ARM) attack.

Measurements for the latter case (Test 7.3) can be a repetition of the Test 7.1 with the transmitter final amplifiers turned off. The low frequency radiations from the system can be measured at a facility such as the Blacktail facility, using the standard technique with a broadband receiving antenna and spectrum analyzer (plus data recorder) and putting the total radar system into operation.

2.5.3.8 Alternate Test Procedures (Test 5.3, 8.3 and 9.2)

As stated earlier, a number of closed-loop test procedures are suggested as alternates to the selected preferred or closed-loop tests, because of either limited facilities, available targets, or restrictions on transmissions. These include Tests 5.3, 8.3, and 9.2.

A closed-loop alternative to measuring range resolution and range sidelobe levels (assuming pulse compression is employed) with real point target returns is to inject the transmitted pulse-waveform, as available from the waveform generator (at either an IF level or RF level) into the IF amplifier or into the RF amplifier (Test 5.3). To accomplish this, the timing of receiver and signal processing operations relative to the pulse initiation (for each repetition interval) must be adjusted to avoid having the simulated target appear at zero range. Resolution measurements would be accomplished as with Test 5.1. The disadvantage of this test method is that the possible effects of the transmitter on response function (usually on range sidelobes) are not included in the test.

An alternative to evaluating ECM vulnerability with field Test 8.1, where simulated ECM signals are radiated from an antenna in the near field, is to couple the simulated ECM signals directly to the radar receiver (at the antenna or RF amplifier) and to inject simulated targets at the same point (Test 8.3). This technique would allow testing without exposing the threat scenarios to possible intercept. However, it has the disadvantage that live target characteristics and clutter cannot be included in the tests without a special simulator which would be unduly complex. The evaluation process with this test would be the same as with the preferred approach of Test 8.1, described in Section 2.6.8.

An alternative to field Test 9.1, described in Section 2.6.10, where live target tests are preferred for evaluating target classification effectiveness, is to use simulated or recorded target signals, typically injected at IF or video. Target classification, depending upon the type of targets and radar functions, may be effected by analyzing phase or amplitude modulations (e.g., turbine compressor blade modulations) or extremely fine resolution (typically range). Hence, simulations would require faithful modelling of such characteristics and recordings of live target returns (if available) would also have to be excellent reproductions in phase and amplitude and possibly have very wide bandwidths. The advantage of this alternative approach (Test 9.2) would be that live targets of all the types of interest for discrimination evaluation may not be available. Test methods for this case would be the same as for Test 9.1.

2.6 Field Testing Procedures

Radar field testing requires that a complete operating radar be placed in an open environment in which targets, clutter, and other source of interference can be coupled through the antenna to the transmitter and receiver. Because the costs for this type of testing are greater than for closed-loop tests, and the test conditions are more difficult to control, field testing must be reserved for evaluation of major radar performance parameters in which the electromagnetic test environment is a critical factor. The test procedures described in this section are representative of such cases.

Data recording for these tests include the test conditions (site, weather, target characteristics, and target flight profile), target position and velocity during each run, radar status, and radar output data. Recording, reduction, and analysis of radar output data would be handled the same as described in Section 2.1.4.2. The measured detection ranges should be extrapolated to those target cross sections of interest (specified), and factors can be applied to account for differences in target fluctuation models (Swerling cases).

2.6.1 Detection Range and Coverage

The best system-level test for radar detection range is conducted with the radar in full operation and with live targets that are calibrated with regard to radar cross section (Test 1.1) The radar should be sited so as to permit an unobstructed view of the region where the single scan probability of detection of the test target is expected to be 50% as well as where the (aircraft) target can safely operate and its position can be accurately determined. Clutter levels within this region should be well below the level for which the detection performance becomes clutter limited (i.e., the clutter levels relative to the receiver noise level, measured in dB, should be at least 10 dB less than the SCV capability of the radar).

The radar should be sited where the foreground terrain is moderately rough (such as grassy, scrubby, or plowed fields) in order to avoid forward scattering from more reflective ground that will introduce lobing in elevation coverage patterns. The latter effect will result in increased detection ranges at the lobe peaks and reduced ranges midway between peaks.

The best target for these purposes is a calibrated reflector such as a metallic sphere, corner reflector, or Luneberg lens type reflector. In most cases, the reflector will be attached to an aircraft, so that it can be easily positioned and moved through the range interval of interest and so that approach speeds can be controlled to either position the target velocity or know the location of the target within the velocity response function of the radar. Ideally, the target speed is controlled to place its approach velocity at the optimum velocity point on the velocity response function. However, this is not always possible, and it is necessary to account for the difference when evaluating the data.

Preferably, a small aircraft will carry the reflector in order to minimize the contribution of the aircraft radar cross section to the overall target cross section, since aircraft cross sections vary significantly with small changes in aircraft aspect angle (toward the radar) which typically result from winds aloft. Also, a constant cross section point target (over a wide aspect angle), such as one of the above calibrated targets, avoids the question of the Swerling fluctuation model. Of the three examples above, the Luneberg lens is especially appealing, since it provides a large cross section as a result of its effective antenna gain. Hence, the cross section of the Luneberg lens reflector will substantially dominate that of a small aircraft. A ratio of cross sections of at least 10 dB is desired.

One problem that a large cross section test target may present is that the range region of interest ($P_d = 50\%$) may be beyond unambiguous range of a radar designed to detect very low cross section targets (e.g., an artillery locator). In this case, the data processing software of the radar may have to be modified to overcome any technique that might be employed to reject ambiguous range targets, and the range ambiguities would have to be accounted for in data evaluation.

In order to obtain a measure of the volumetric coverage of the radar, test runs should be made at three or more target altitudes to obtain elevation coverage profiles. At least ten runs should be made at each level, in view of the statistical nature of the detection process. Target position data, accurate to ±5% of detection range, can usually be obtained from the navigation equipment on board the aircraft, but can also be obtained from other measurement systems such as a nearby tracking radar. The Fort Huachuca Instrumented Test Range (ITR) offers a capability that is far more precise than is required tor these detection range measurements.

Target velocity data can be obtained from the aircraft on-board instruments and may be obtained from the radar itself (if velocity measurement is a function within the digital subsystem). Approach velocity accuracy of ±5% is sufficient. Again, the ITR offers more capability for accurate velocity measurement than is required.

In determining the volumetric coverage of a radar with an electronically scanned antenna, at least three azimuth scan angles should be evaluated, since antenna gain varies with scan angle. The antenna (or radar) may be mechanically rotated in order to keep the test target operations within the assigned flight zone.

2.6.2 Subclutter Visibility (SCV) Tests 2.1 and 2.2

Although the most realistic method for this measurement would be to operate the radar against a live target and a background of live clutter, this approach presents some difficulties due to uncertainties regarding the clutter signal level within the same resolution cell as the target at any specific time during the test. The preferred method is to use live clutter which is phase modulated to simulate a moving target (Test 2.1). [7] In this procedure, a calibrated phase modulator is inserted in series with the first local oscillator (as shown in Figure 2.6.2, the IF reference oscillator, or the signal path (typically, at the IF level). By shifting the phase between alternate pulses by the same amount, the received clutter signal is modulated to achieve the effect of a target at optimum velocity (doppler frequency equals 1/2 PRF) and optimum phase being superimposed upon all the received clutter (i.e., within all range gates). The simulated target-to-clutter ratio is dependent on the degree of phase modulation, and the optimum phase condition results in pure phase modulation without accompanying amplitude modulation.

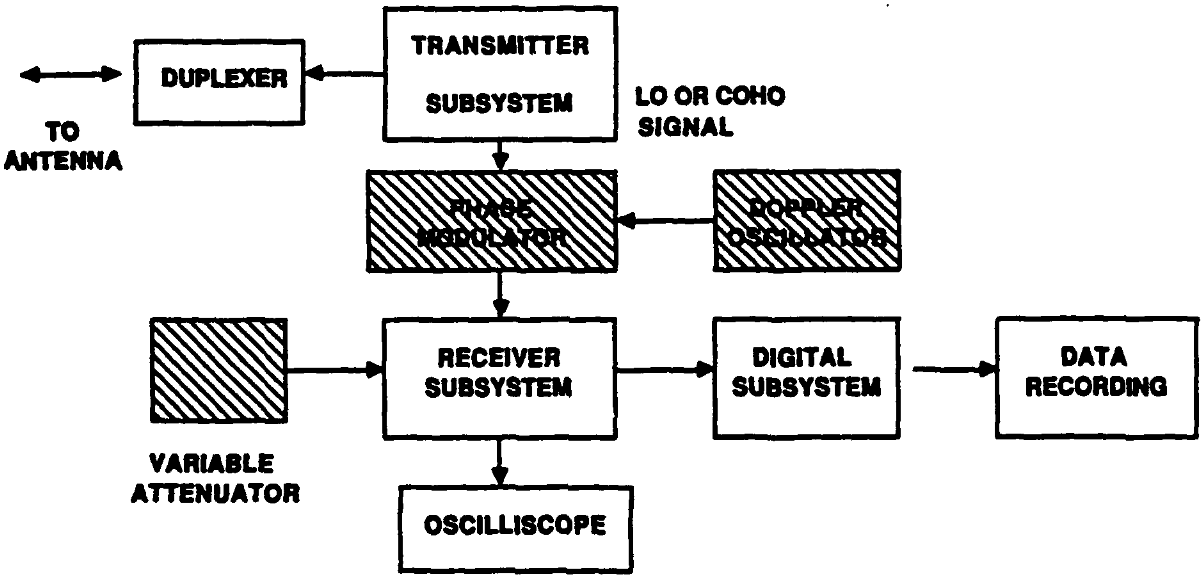


Figure 2.6.2, Subclutter Visibility Measurement

= *TEST EQUIPMENT*

The procedure for conducting this test is as follows:

(1) Choose a strong isolated clutter point and set its level by adjusting the preamplifier gain or an RF attenuator (see Figure 2.6.2) so that it just saturates (maximizes) the receiver output (as observed with an oscilloscope).

(2) Observe the output of the signal processor for the resolution cell containing the selected clutter point and increase the phase modulation until a 50% probability of detection is obtained.

(3) The amount of phase modulation is then converted to SCV by applying a number of factors.

One conversion factor relates the modulation to a clutter-to-target ratio. One way of doing this is to modulate a CW signal with the phase modulator and use a spectrum analyzer to measure the sideband-to-carrier ratio. This ratio is 3.92 dB larger than the equivalent target-to-clutter ratio.

Another factor that may be applied in the process of comparing the results of the test with specified performance is that relating the SCV at optimum velocity to the average over the velocity response function. This factor depends upon the shape of the velocity response function. It is typically the ratio of the average value of the response function over the specified target velocity spread taken over the response level at optimum velocity.

One more correction that may be applied accounts for the optimum phase condition of the test. This factor accounts for the signal loss that would normally occur under strong clutter conditions, when the clutter is at or above the receiver saturation level and the non-optimum target phase conditions result in the loss of the target energy contained in AM sidebands. This factor ranges between 1.5 and 3 dB, depending upon the amount of non-coherent integration employed.

This test method can be accurate to about 1 dB. Its only disadvantage is that the phase modulator may have to be a special design. Even though this circuit is relatively simple, it is not generally found as a catalog item.

Siting of the radar for this test can be the same as for the detection range measurements above, providing that one or more strong single points of clutter (e.g., towers, water tanks, mountain cliffs, etc.) are within radar view and at sufficiently close range to provide clutter return signals equal to or greater than the ratio of SCV over the receiver noise level. Finding such clutter sources at Ft. Huachuca doesn't appear to be a problem. Scott Peak presents

a potential point to use, and the AN/FPS-16 on Scott Peak could be used as a strong fixed point of clutter by pointing its antenna directly at the test radar. The latter case would result in a fixed target (clutter) of several thousand square meters.

An alternate SCV test procedure (Test 2.2) is that of superimposing (at RF or IF) a signal generator synthesized target on live clutter, which has the advantage of not requiring a special phase modulator since generally available test equipment is used. However, the latter test equipment may be expensive if pulse compression waveforms are used by the radar. Also, the test target signal should be gated in range and angle to place it where the point target appears and errors in the measurements may result from misalignment between the two signals.

This measurement is conducted much the same as Test 2.1 above, with the clutter level set at the receiver saturation level. Calibration is achieved by equalizing the amplitudes of the two signals as viewed at a point in the receiver before saturation occurs. The measurement is then made by reducing the amplitude of the test signal until 50% probability of detection is obtained at the signal processor output. The SCV is then equal to change in the signal generator attenuator, corrected for the ratio of average velocity response to response at the target velocity used in the measurement.

The need for knowing the simulated target velocity (to within ±5% of the PRF) suggests that an IF signal would be preferred because of the relaxed signal generator stability requirements (as compared with RF injection). Exceptions to this argument would result from concerns about nonlinearities in the RF amplifiers or the existence of a highly versatile and stable RF signal generator in the inventory.

Depending upon the emphasis placed on radar operation in rain, snow, and chaff, as well as the design of the velocity response function to effectively reduce their effects, it may be required to repeat SCV measurements under these clutter conditions. In this case, the above tests would be repeated under conditions where these forms of clutter occur, with added difficulties of calibrating the tests (and probable reduced accuracy of measurement) caused by the changing with time of the characteristics (cross sections, spectra, etc.) of the clutter.

These forms of clutter, being driven by wind, have similar characteristics. They typically have (frequency) spectra widths dependent upon the wind shear and turbulance and, as compared with ground clutter, they are offset in doppler frequency as a result of the average wind speed component in the direction of the radar. Thus, SCV measurements with chaff would not only cover that clutter form, but would be representative of SCV performance with weather (various forms of precipitation) and to some degree could be extrapolated to these cases through analysis based on available weather and chaff clutter models.

2.6.3 Target Acquisition Time (Test 3.2)

An alternate method (to closed-loop Test 3.1) for measuring target acquisition time with either an electronically scanned system that performs both search and track functions or with a track-while-scan system is to use a live target. This test (no. 3.2) can be accomplished by recording the data processor outputs, as described in Section 2.4.1.2 (including a time tag on each data report, if the output data does not already include time) and observing the time difference between the first reported detection of a target and the reporting of a target track being established. This test can be carried out as an adjunct to the measurements of detection ranges (Test 1.1).

2.6.4 Resolution in Four Radar Coordinates (Test 5.1)

The preferred method for measuring range resolution and range sidelobes with a radar employing pulse compression is with an isolated point target such as the clutter signal used in the SCV tests (tests number 2.1 and 2.2). This approach offers the advantage over closed-loop Test 5.3 in that it includes the effects of the transmitter power amplifier (such as amplitude limiting and phase ripple), particularly as they affect range sidelobes.

Figure 2.5.3 applies to the range dimension (x = range), with the sidelobes being the time sidelobes of the pulse compression technique and its implementation [8]. In this case, the dimension is approximately equal in time to the reciprocal of the signal bandwidth, with the degree of approximation being dependent upon the weighting (amplitude and phase) that is employed to control sidelobe levels. The extent of the sidelobes in time is equal to approximately twice the length of the transmitted pulse.

This test (number 5.1) would be conducted with the same test configuration as with the SCV tests (number 2.1 and 2.2), but without simulation of moving targets (by injection or modulation). With a sufficiently strong point target return (as required for the SCV tests, and typically more than 40 dB above the receiver noise), sampling the range gate outputs with the signal processor over the range interval centered at the target range having a width corresponding to twice the transmitted pulsewidth. A test point within the signal processor may provide this data to be observed on an oscilloscope or the data may be available to be called up to the radar display for diagnostic purposes. This test should be an adjunct to the SCV tests (number 2.1 and 2.2).

2.6.5 Angle Tracking Response (Test 6.1)

The closed-loop response of the angle tracking servo loop, including the antenna and receiver, is best evaluated on a target signal radiated from a boresight tower. Two types of response should be measured: step response, and frequency response.

2.6.5.1 Step Response

A target signal is radiated from the boresight tower at a level well above noise (e.g., + 30 dB), and the radar is locked onto this signal in all tracking coordinates. The angle tracking loop is then switched to manual, and the beam is displaced by 1/10 beamwidth in azimuth from the target. The azimuth data are recorded while the loop is switched to automatic track, and the step response is observed in the recorded data. Analog, (strip-chart) recording of a DC error signal may be used, but in digital loops the error and beam position should be recorded digitally, at a rate at least four times the loop bandwidth.

The test is repeated in the elevation coordinate.

To test the ability of the receiver AGC (or other normalization) to hold constant tracking loop gain on weak signals, the tests should be repeated for S/N ratios of +10Db, +5dB, and 0dB (or as low as the radar will continue to track). It can be expected that the reduced loop gain for weak signals will produce a more sluggish response. The presence of loop visibility (large overshoots in response, oscillating at a frequency well below the servo bandwidth) may also be disclosed at certain low values of S/N ratio.

2.6.5.2 Frequency Response

The angle loop is locked on the strong boresight tower source as in the step-response test. A low-frequency function generator signal is added into the error signal amplifier, and adjusted to produce 1/10 beamwidth (e.g.0.1 Hz). Peak beam deflection is recorded as the frequency is varied up to and beyond the nominal loop bandwidth. Azimuth and elevation loops are tested.

For digital loops, the function generator signal is passed through an A/D converter before being added to the receiver error signal. Alternatively, a variable-frequency sine wave may be generated digitally and added to the error signal.

The boresight tower signal is then reduced to levels of +10dB and lower, in steps, to obtain the loop frequency response as the signal approaches the minimum for tracking. Loss of high-frequency response, and development of peaks in the low-frequency response, may be expected.

2.6.5.3 Servo and Receiver Noise

Angle output data are recorded while tracking the boresight tower signal, without externally generated error signals. Samples of data are taken in each coordinate as the signal level to reduced in steps to the minimum at which tracking is possible. The rms value of beam position error, relative to the source, is determined for each value of S/N

ratio. The limiting value for high S/N will indicate the level of noise in the servo loop, while the curve of error vs S/N will measure the antenna and error detector slope constant for thermal noise.

2.6.6 Angle Tracking Accuracy (Test 6.2)

The purpose of this test is to establish the absolute angle accuracy of the radar system under field operating conditions. Previous analysis will have established the expected contributions of the following major error sources:

- Thermal noise
- Target noise (glint and scintillation)
- Clutter
- Jamming
- Multipath
- Instrumental error in the radar

These components of error will vary with the scenario, and a limited number of realistic scenarios must be defined which will permit evaluation of the radar angle response to each component. Suggested step-by-step procedures, with scenarios chosen to isolate each component, are described below.

2.6.6.1 Thermal Noise Test

A well defined point target is provided by mounting a corner reflector, Luneberg lens, or repeater on a small target aircraft or drone. The target is flown at a range such that S/N ratios near +10dB are observed at elevations high enough to avoid clutter and multipath errors. If necessary, radar power is reduced to obtain this level within the instrumented range of the radar. The standard deviation of the angle data from a smoothed target trajectory provides a measure of thermal noise, at low S/N ratio, and the limit as S/N ratio is increased represents the instrumental error of the radar system.

2.6.6.2 Clutter and Multipath Error Test

The well defined target from the thermal noise test is flown at reduced elevation angles to produce errors from clutter and multipath. The target trajectory is selected to pass from a region in which strong clutter is coincident in range with the target to a region in which the target is relatively free of clutter. The terrain contributing multipath errors should be as near constant as possible, to permit the isolation of the clutter error component as clutter varies.

Recorded target data are compared with reference data from optical or instrumentation radar (e.g. ANFPS-16), keeping in mind that the instrumentation radar may also have multipath errors at low elevation angle. If the siting is chosen to permit the instrumentation radar to track at shorter range (and higher elevation angle) than the radar under test, this problem may be minimized . The differences between recorded target data and the true target position represent the combined effects of the several sources listed above (plus possible atmospheric refraction, which can be calculated and removed from the data). The thermal noise and glint can be minimized by use of a large reflector or other source. Jamming is absent, and the target trajectory is selected to produce clutter and multipath which exceed the instrumental error.

The clutter and multipath components can also be separated from each other by running the same test trajectory with large and larger reflectors, to reduce the relative importance of clutter. Small reflectors cannot be used to increase relative clutter unless the physical size of the target vehicle is small enough to avoid significant glint and suntillation components.

2.6.6.3 Target Noise Test

A target is flown without enhancements, providing realistic glint and scintillation. The trajectory is selected to provide a strong signal from an elevation high enough to minimize clutter and multipath. Recorded data are analyzed to obtain rms deviations from the true trajectory.

Flights at different ranges can be scheduled to isolate the glint errors from scintillation errors. Glint is represented by a constant deflection in meters at the target, and hence the angle error varies inversely with range. Scintillation produces a constant angle error, independent of range, if the target spectrum (i.e., rate of rotation about the radar line of sight) remains constant. This rate can be held essentially constant by flying the target with a rate of turn which greatly exceeds the azimuth angle rate observed by the radar.

2.6.6.4 Jamming

The angle error effects of jamming are tested by adding the jammer emission to any other test environment, and comparing results. Because many jamming techniques are based on enhancement of a naturally occurring phenomenon, it may not be possible to evaluate the jamming errors under conditions when other errors are low. For example, surface-bounce jamming is most effective at low elevation angles where there is already some multipath error. Certain impulse jammers have their greatest effect when the radar is attempting to reject clutter with coherent processing of many successive pulses.

The jamming scenario specifies the types of jamming, locations of the jammers, frequencies and waveforms, effective radiated power levels, and timing of the jammer actions. These parameters must be selected to represent the specified threat against the particular radar under test.

2.6.7 Electromagnetic Compatibility (EMC) (Test 7.3)

Section 2.5.3.8 describes closed-loop tests of Electromagnetic Interference (EMI) levels emitted by the radar under test. The tests for effects of EMI or intentional disruption of the radar by electromagnetic radiation are categorized as field tests, since the complete radar is involved (although the transmitter final power amplifier does not need to be turned on). The radar specification, based on the anticipated threat, may specify EMI levels over the full electromagnetic radiation spectrum (DC to millimeter wavelengths) to which the radar may be subjected (externally) without impairment of radar performance as a result of excessive spurious signal levels entering the receiver, exiter, waveform generator, digital signal processor, data processor or display.

This test, which could be conducted at the Blacktail facility, would consist of the generation and radiation of CW and pulse signals at the specified frequencies (or frequency bands) and power levels (measured at the outside of the radar shelter). The radar would be in operation, except for the final power amplifier. As the test signal frequencies, power levels, and wave forms (CW, pulses of various widths and PRF's) are varied, the IF receiver and radar output would be monitored. Visual monitoring would be accomplished with an oscilloscope connected to the IF amplifier outputs and at the radar output by the display. These points could also have recorders connected to record all data during the test. However, recording the IF channels requires recording bandwidths equal to the IF amplifier bandwidths.

Future radars may be concerned with intentional disruption by directed high powered electromagnetic energy. Typically, the frequencies of concern would be from the low end of the radar band up into the millimeter wave region (above the waveguide cutoff frequency). The effects of such radiation would include receiver saturation and burnout. Testing for these effects would be conducted the same as above, with the far-field generation of the specified energy levels measured at the radar antenna. In this case, simulated targets should be injected at RF, either by a signal generator located in the antenna near field or from a boresight test tower. The radar output data and display would be monitored for saturation effects (desensitization), front end burnout (total loss of signal), or excessive false alarms. An alternative to simulating target signals is to operate the radar at full power and monitor returns from strong fixed targets (clutter).

2.6.8 Vulnerability to ECM (Tests 8.1 and 8.2)

Modern tactical radars must be prepared to operate in an ECM environment. Hence, the radar specification typically includes an ECM threat model.

A variety of ECM techniques may be employed by attack aircraft carrying jammers to defeat certain types of battlefield radars or by ground vehicles with jammers to defeat airborne (and RPV) radars. ECM techniques that may be used against search and acquisition radars would include repeaters or noise pulses to saturate target handling circuits and noise jammers for the same purpose or to desensitize detection circuits. Techniques used against tracking radars would include repeaters which effect range-gate and velocity-gate pulloff, the so-called phase-front techniques (cross polarization, cross-eye, and terrain bounce) as well as noise jammers. High powered standoff jammers are tyically deployed well behind the FLOT in a number of large aircraft at high altitude. They generally produce barrage jamming with wideband noise to counter all of the opposing radar types within the battle area, and attempt to introduce strong enough signals through the radars sidelobes to greatly reduce their effectiveness regardless of their mainbeam pointing directions.

The procedures for testing the vulnerability of radar to ECM (Test 8.1) are essentially the same as the detection range measurement procedure (Test 1.1) and the live target test for tracking accuracy (Test 6.2), with simulated ECM injected into the radar antenna by means of a small antenna (e.g., a horn antenna) in front of the radar antenna. The simulator signal generator could consist of a set of waveform generators modulating an RF power source, a set of actual jammers, or the non communications simulator of the EMETF at Fort Huachuca. The latter has substantial versatility for generating radar type signals over the frequency bands of interest and should be capable of simulating many types of ECM, with the possible exception of noise jamming. Hence, the EMETF may have to be augmented with a noise jammer (or simulator).

In conducting ECM vulnerability tests with search and acquisition radars (or search and acquisition modes), the detection range limitations and the target acquisition probabilities should be determined as a function of the types of ECM and the ECM power levels. An alternative is to be establish the ECM power levels at the antenna corresponding to the specified threat and determine if the radar performance parameters (detection range, etc.) are met.

Evaluation of the effects of ECM on tracking radars should be based on the tracking errors as a function of ECM levels (as compared with the specification) and ECM levels at which tracks are broken or lost.

Future radars, designed to cope with strong ECM environments, may incorporate antenna sidelobe cancellation techniques or adaptive (antenna) arrays for the purposes of negating the effects of a few powerful jammers that would otherwise upset radar operation by entering the receiver through antenna sidelobes. Typically, standoff jammers are of concern in this situation.

Sidelobe cancellers and adaptive arrays can be effectively evaluated only by testing on an antenna range or in conjunction with field measurements of detection range and tracking accuracy, with the simulated jammer sources in the radar antenna far field. Thus, the recommended approach to evaluating the ECM vulnerabilities of radars incorporating these techniques (test no. 8.2) is to conduct tests as described above, using live targets, with simulated jammers (or real jammers, if available) located at diverse points in the far field regions of the radars. The number of jammer sources to be used in each case should equal the number called out in the radar performance specification, since cancellation performance and other radar performance measures (e.g. tracking accuracies) are dependent upon the number of jammers (and number of canceller loops employed). Noise (jammer) sources are usually preferred for these tests, since the threat of concern is of the standoff type.

2.6.9 Testing Vulnerability of Radars to Interception and Location (Test 8.4)

Past radar test and evaluation programs have concentrated on performance of the radar in target detection, tracking, or imaging, with and without interference from clutter, ECM, and other signals. New emphasis on vulnerability of radar signals to intercept and location, including homing by ARM seekers, requires the development of new test methods and facilities.

2.6.9.1 Vulnerability of Conventional Radars

Conventional radars may be defined, with respect to intercept of their signals, as radars in which pulse widths in the order of 0.1 to 100 μ s are transmitted, with or without pulse compression modulations. Such radars, used for battlefield reconnaissance, intrusion detection, navigation, air defense, and hostile weapon location have long been the target of intercept and warning receivers, and more recently of anti-radiation missles (ARMs). Their vulnerability to these EW devices results from the relatively large two-way path loss involved in the basic radar-target geometrical situation, as compared with the one-way loss for the intercept receiver.

The one way advantage for an intercept receiver located on the target, compared with the radar can be written [1, p. 12]:

$$Q = \frac{S_i}{S} = \frac{A_i}{A_r}\frac{4\pi R^2}{\sigma}$$

where S_i is the signal power available to the intercept receiver, S is the signal power available to the radar receiver, A_i is the effective aperture area of the intercept system antenna, A_r is the effective area of the radar antenna, R is the target range and σ is the target cross section.

In a typical case, R = 30 km, $\sigma = 1.0\ m^2$, $A_i = 1.0\ m^2$, and $Q = 10^9 = 90$ dB. This means that the intercept receiver can afford to operate over an entire radar band (e.g., B = 1 GHz) or even over an octave band (e.g., 8 to 16 GHz) with severe mismatch to the radar transmitted signal, while retaining high probability of intercept of the radar signal.

2.6.9.2 Vulnerability of LPI Radars

Some modern radars are designed to use special frequencies, waveforms, low-sidelobe antenna patterns, and operational procedures to reduce the vulnerability to intercept. Such radars are described as "low probability of intercept" (LPI) radars. Options in the design of these radars include the following:

(a) Reduced average power, or "power management";
(b) Reduced peak power (e.g., CW or modulated CW);
(c) Wide signal spectra (e.g., wideband modulation, *frequency hopping*);
(d) Low transmitting antenna sidelobes;
(e) sporadic transmission;
(f) Selection of frequencies in densely occupied bands;
(g) Selection of frequency and waveform to simulate communicate signals;
(h) Selection of frequencies in atmospheric absorption bands.

2.6.9.3 Evaluation Requirements

The process of evaluating vulnerability to interception of both conventional and LPI radars is closely related to the evaluation of the intercept receivers. Indeed, many LPI radar analyses depend, for low vulnerability, on postulation of intercept receiver characteristics which are most ideally mismatched to the radar signal. In the absence of a set of standard intercept receiver characteristics, against which to evaluate a radar, any radar with any waveform can be claimed to have "LPI" properties.

An initial step in evaluation is then to establish the intercept receiver threat models against which the radar is to be evaluated, whether by analysis, computer simulation, closed-loop (indoor) test, or field test. The definition of these models must be done by a DOD organization familiar with the existing intercept receiver technology and with future

trends and forecasts in this technology and its probable deployment. Different models are needed for strategic reconnaissance, tactical reconnaissance, radar warning receivers, look-through receivers of ECM systems, and ARM seekers.

2.6.9.4 Electromagnetic Environment

Most LPI approaches are valid only in dense signal environments, where the intercept receiver is, in effect, jammed by a multiplicity of irrelevant signals. Evaluation of radar vulnerability to intercept depends on the production, at the intercept receiver, of a realistic suite of such interfering signals. Again, models for this environment are best produced by those organizations which deal with complex EW scenarios.

2.6.9.5 Physical Environment

The vulnerability of the radar to signal intercept depends, in many cases, on the physical surroundings of the radar. Factors include the following:

(a) Atmospheric and weather attenuation of the signal;
(b) Scattering of the signal by terrain or cultural features;
(c) Scattering of the signal by rain or chaff;
(d) Masking by terrain.

For example, if low-sidelobe antenna features are depended upon to prevent the signal from reaching the intercept receiver, scattering from sources within the main beam can provide an unwanted path to the receiver. The accuracy of location in this case may not be adequate for the intercept system (e.g., ARM seeker), but the receiver may be cued to the correct frequency and waveform by the scattered signal.

Models are available for analysis and simulation of these environmental effects, but field testing may be necessary to validate the models.

2.6.9.6 Test and Evaluation Facilities

To a large extent, the facilities required for evaluation of intercept vulnerability are available as by-products of existing EW test programs. For example, at AEPG there are many types of ESM equipment, either under evaluation or in use as support equipment for other programs. The EMETF is equipped with advanced "stress loading" simulations to produce EM environments according to standardized scenarios for different military situations. While this equipment has been designed to test intercept receivers, communications receivers, and radar receivers, it can also serve as the background environment

for evaluation of vulnerability of the conventional or LPI radar system to intercept of its signals. Antenna test facilities, suitable for many varieties of radar antenna are installed at AEPG.

The additional facilities needed for complete evaluation of LPI radar systems include the following:

(a) Special LPI waveform generators to simulate the signals from certain new radar designs, in closed-loop tests;

(b) Antenna pattern generators to simulate the low sidelobes of new antenna designs, in sectors far from the main lobe;

(c) Multipath scattering models to simulate the effects of a number of standard terrain situations and radar siting options;

(d) Field test sites, chosen to represent these terrain situations, to validate the simulations and closed-loop test results on vulnerability to intercept;

(e) Generic airborne intercept and seeker receivers, to be used in the field tests to validate the indoor test results and to provide data on location and homing accuracy (not readily obtained through simulation and closed-loop testing);

(f) Field environment signal generators, to amplify and radiate the EM environment of the closed-loop models toward the airborne receivers during field tests involving the actual radar equipment.

2.6.10 Target Discrimination (Test 9.1)

Future radars may incorporate techniques for separating different types of targets for the purposes of classifying or identifying them and establishing threat situations. These techniques typically exploit unique phase or amplitude modulation effects of given target types or extremely high range resolution.

The preferred method for evaluating these classification techniques is with live targets of the types of interest, including both the types to be recognized and types which represent possible false recognition. These tests would be conducted in the same manner as the detection range measurement tests, with the evaluation criteria based on the target discrimination or classification specification.

Section 2.5.3.9 describes an alternate approach for this test, where simulation or recorded target signals would be used when live targets are not available. Another possibility is to conduct the field tests with those targets that are available and augment these tests with recorded target signals if they are available to cover the cases where live targets cannot be obtained.

2.6.11 Airborne Radar Special Requirements (Tests 10.1 and 10.2)

The normal operating conditions for airborne radars clearly establish some special requirements for conducting field tests, since field conditions include in-flight operation. However, many field tests can be run on the ground and should be done in this manner in order to avoid undue expense of flight operations.

Essentially, all of the above closed-loop and field tests can be conducted on the ground, with the radar preferably located on a high mount, such as a rooftop or at the edge of a cliff. Thus, ground effects (e.g. multipath propogation and clutter) are more like those when the radar is airborne at low altitude.

The SCV measurements effected in a rooftop environment represent the inherent capabilities of the radar above and must be interpreted in the light of typical flight conditions. For example, SCV in flight is reduced from the inherent measure above as a result of clutter spectral spreading due to aircraft motion and imperfect own slip velocity compensation by the inertial measurement unit (IMU). However, the rooftop measurement is an important benchmark, and, for a given set of radar characteristics (including velocity response), only the velocity compensation subsystem will contribute to SCV deterioration below that which can be analytically derived from the above benchmark measurements and the radar characteristics.

Airborne (flight) tests (Test 10.1) should be conducted under representative clutter conditions with live targets to obtain qualitative and semi-quanitative (knowing the type of clutter and approximate moving target cross section) measurements. These observations and test results can then be compared with the expected performance measures derived from the benchmark tests.

Of particular interest are the cases of airborne mapping radars, such as might be deployed on RPV's. For these radars, non-coherent mapping can be evaluated by flying over representative target areas and recording maps with whatever recording equipment is contained within the system or with additional recording equipment (Test 10.2). Map fidelity and accuracy can be evaluated at Fort Huachuca by mapping the Radar Geometric Fidelity Facility, or "Dry Lake" facility.

Synthetic Aperture radars (SAR) can only be fully tested for map quality, resolution, and accuracy by flight testing. The mapping and recording procedures apply here, as well but the scenes selected should provide the opportunity to observe and measure the finest resolutions specified. The Fort Huachuca Radar Spoke/Resolution Facility is an excellent subject for these tests. The Instrumented Test Range facilities can also be used to determine the precise locations of the test aircraft for overall mapping system accuracy measurements.

2.7 Radar System Examples

In order to make more specific the generic test procedures described in Sections 2.4 - 2.6, five typical sets of radar characteristics are given in this section, and test procedures for these radars are described in greater detail. The radars include examples from the three major types which may require testing at AEPG:

- Weapon location radars,
- Short-range air defense search radar,
- RPV-based battlefield surveillance radars.

2.7.1 Weapon Location Radars

Two types of radar for weapon location are used as examples:

- Artillery location radar (Table 2.7.1)
- Mortar location radar (Table 2.7.2)

The two systems differ in that greater range and sensitivity are required for artillery location. Location accuracy is the same for the two systems.

TABLE 2.7.1 **Artillery Location Radar**	
Assumptions:	
Location: 20 to 30 km behind FLOT	
Maximum Detection Range: 30 km on 0.001 m^2 target	
Maximum Radial Velocity of Artillery Round (as seen by radar): 500 m/s.	
Operation: Single bar scan at 2-3° elevation above terrain mask for search. Automatic scan back on detection to verify. PRF switching during search and acquisition to avoid blind speeds and identify multiple-time-around echoes. PRF selection to avoid blind speeds in tracking. Scheduling of multiple target tracking while continuing search. Reverse "prediction" to locate artillery weapons (with CEP of 15 m).	
Characteristics:	
Wavelength λ	10 cm
Antenna: Type	Phased array (phase-phase), monopulse
Dimensions: Aperture	Height: 4m, width : 2m
Beamwidths:	Elevation : 1.5°, azimuth : 3°
Scan Coverage:	90° Az x 15° El
Scan Rate:	90° Az in 1 sec.
Gain	37 dB
Polarization	Linear Vertical
Sidelobes	-35dB peak (Az), -45 dB rms
Transmitter: Type	TWT or solid state
Peak Power	10 kW
Average Power	1 kW
Tuneable Bandwidth	250 MHz
Waveform: Pulsewidth	20 μs

Pulse Compression	50:1
PRF's	Selected from 5 (nominal 5 kHz)
Receiver: Type	Double conversion, with STC and Az + El monopulse channels
Bandwidth Instantaneous	2.5 MHz
Noise Factor	3 dB
Tuneability	250 MHz
Linearity	± 1 dB over 100 dB range
Signal Processor: Functions	Quadrature Channel A/D's Clutter filter FFT CFAR/scaling Thresholding ECCM Tracking Target reporting Prediction
Improvement Factor	65 dB
Visibility Factor	10 dB
Coherent bandwidth	180 Hz
Dwell time-search	17 ms
Dwell time-track	5.5 ms
Noncoherent integration	3 pulses
Control & Data Processing:	
Type	Microprocessor based multiprocessor
Modes	Turn on, schedule, search, verify/acquisition, track and predict, display and test
Display: Type	Digital, printer

TABLE 2.7.2 MORTAR LOCATION RADAR	
Assumptions: Location	8 to 10 km behind FLOT or, defend 4 km diameter area with 3 systems.
Maximum Detection Range:	10 km on $0.003m^2$ target
Maximum Radial Velocity of Mortar Rounds (as seen by radar):	150 m/s (f_d = 10kHz, when λ = 3cm)
Mortars:	60 mm, 81 and 82 mm, 120 mm
Operation:	Single bar scan at 3° to 4° elevation above terrain mask for search, automatic scan back on detection to verify, with PRF switching to identify multiple-time-around echoes. Schedule multiple target tracking while continuing search. Reverse "prediction" to locate mortar tube (with CEP of 15 m)
Characteristics:	
Wavelength (λ)	3 cm
Antenna: Type	Phased array (phase-phase), monopulse
Diameter (aperture)	1.0 m
Beamwidth (Az + El)	2°
Scan Coverage	120° Az x 20° El
Scan Rates	120° Az in 3 sec
Gain	36 dB
Polarization	linear vertical
Sidelobes	-35 dB peak, - 45 dB rms
Transmitter: Type	TWT or Solid State
Peak Power	10 kW
Average Power	1 kW
Tuneable bandwidth	500 MHz

Waveform:	6.5μs pulses 13:1 pulse comparison to 0.5 μs 3 PRFs 15 kHz nominal
Receiver: Type	Double Conversion, with STC and Az and El mono-pulse channels
Bandwidth (instantaneous)	2 MHz
Noise Factor	3 dB
Tuneability	500 MHz
Linearity	± 1 dB over 100 dB range
Signal Processor: Functions	Quadrature channel A/Ds Clutter filter FFT CFAR/scaling Thresholding ECCM Tracking Target reporting Prediction
Improvement Factor	±60 dB
Visibility Factor	+13dB
Coherent Bandwidth	60 Hz or 240 Hz
Dwell time	25 ms
Noncoherent integration	1 or 4 pulses
Control & Data Processing:	
Type	Microprocessor-based multiprocessor
Modes	Turn-on
	Search (simple bar search, 3° above terrain mask)
	Track & Predict
	Display (control) and test
Display: Type	Digital, Printer (Weapons coordinates)

2.7.2 Search/Acquisition Radar for Short-Range Air Defense

This radar is typical of systems which may be required to support short-range missle systems using radar or electro-optical guidance. The range is sufficient to detect threats, to form track files in the associated computer, and to designate these threats to the appropriate missle unit.

TABLE 2.7.3 RADAR FOR SHORT-RANGE AIR DEFENSES	
Assumptions:	
Location:	10-20 km behind FLOT
Purpose:	Detect low-flying aircraft and helicopters and provide target acquisition data to short range air defense system employing guns or missiles (typically employing infra-red or optical guidance) or both.
Maximum Detection Range:	20 km on $1.0m^2$ target
Maximum Radial Velocity of Target:	Mach 0.9 (302 m/s)
Operation:	Search volume 360° Az x 3 km height x 20 km range Provide track-while-scan data and target vectors to missle launch controllers and fire control officer on targets that meet "threat" criteria (e.g., approaching targets, velocities, no IFF, etc.).
Characteristics:	
Wavelength λ	3 cm
Antenna Type:	Mechanically scanned flat plate, csc^2 elevation pattern
Dimensions: (Aperture)	1 m width x 0.25 m height
Beamwidths:	Azimuth = 1.7°, elevation = 8.5° sc2
Scan Coverage:	360° azimuth
Scan Rate:	360°az in [illegible] sec.
Gain:	30 dB
Polarization:	Linear Vertical
Sidelobes:	40 dB peak (Az), 50 dB rms
Transmitter:	
Type:	TWT or solid state
Peak Power:	1 kW
Average Power	50W
Tuneable Bandwidth	1GHz

Waveform: Pulsewidth	6.7 μs
Pulse Compression	13:1
PRF's	4, nominal 7.5 kHz
Receiver: Type	Double conversion, with STC
Bandwidth, (Instantaneous)	2 MHz
Noise Factor	3 dB
Tuneability	1GHz
Linearity	± 1 dB over 100 dB range
Signal Processor: **Functions**	Quadrature channel A/Ds Clutter filter FFT CFAR thresholding ECCM Track-while-scanning Target reporting
Improvement Factor	45 dB
Visibility Factor	10 dB
Coherent Bandwidth	300 Hz
Dwell time	14 mμs
Non-coherent integration	4 pulses
Control & Data Processing: Type	Microprocessor/multiprocessor
Modes	Turn-on/turn-off Schedule TWS tracking Display Test
Display: Software	Digital Printer Data to launcher

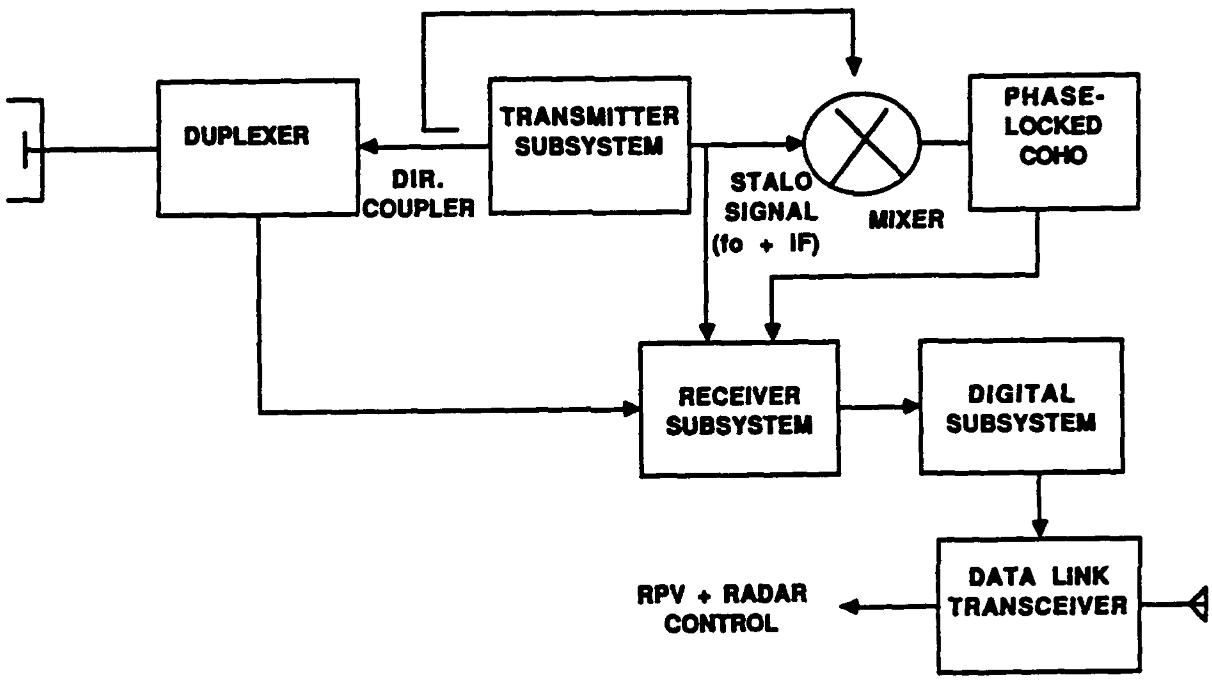
2.7.3 RPV-Based Battlefield Surveillance Radar

Two RPV radars are postulated as potential candidates for testing at Fort Huachuca. The first is a conventional real-beam mapping radar, with ground moving target indication (GMTI), and the second is a side-looking synthetic aperture radar (SAR) for high resolution mapping.

2.7.3.1 Real-Beam Mapping Radar

This radar is presumed to be mounted as a chin (under the RPV nose), and to utilize a mechanically scanned antenna. Low cost and high reliability are required, hence a relatively simple design is envisioned.

The transmitter is assumed to be a magnetron with coherent MTI achieved by means of a phase-locked coherent oscillator (as shown in Figure 2.7.1.). The transmitter subsystem includes a stable local oscillator (STALO) and the magnetron plus power supply. The receiver and digital subsystems are essentially the same as shown in Figures 2.2.2 and 2.2.3, except that they would be relatively simple in that the receiver (as shown) is a single-conversion type, and the digital processors would have only 2 or 3 modes of operation. The frequency band of operation is selected as k_u-band.



2.7.1 Simplified Block Diagram Of Phase-locked Coherent Radar

On board digital control and signal processing is incorporated in the radar, with map data and moving target data transmitted to the ground by means of a microwave data transmission link. A ground station would receive the latter transmissions and display the maps as well as to track and display moving target reports. The RPV and the radar (turn on, turn off, etc.) would be controlled from the ground station. The RPV would typically operate in the altitude region of 1500 to 3000 m and would travel at speeds 150-250 m/s. The maximum ranges of interest would be about 15 km.

The characteristics of this radar are given in Table 2.7.4.

TABLE 2.7.4 REAL-BEAM MAPPING RADAR	
Assumptions:	
Purpose:	Terrain mapping for location of terrain features, fixed (man made) ground targets (e.g. military installations) and military vehicles such as trucks and trailers (both moving and parked).
Aircraft Operation:	1500 - 3000 m altitude, 150 - 250 m/s.
Maximum Detection Range:	15 hours on 10 m^2 target
Range Resolution:	15 m
Operation:	Continuous scan (looking down) over 360° azimuth
Characteristics:	
Wavelength:	1.8 cm.
Antenna: Type	Mechanically scanned, flat plate, csc^2 elevation pattern. Radome
Dimensions: (Aperture)	0.6m width x 0.3m height
Beamwidths:	Azimuth = 1.7° elevation = 3.4°, csc^2
Scan coverage:	360° azimuth
Scan Rate:	360° azimuth in 5 seconds.
Gain:	34 dB
Polarization:	Linear vertical
Sidelobes	40 dB peak, 50 dB rms
Transmitter:	
Type	Magnetron
Peak power	20 kW
Average power	12 W
Tuneable bandwidth	200 MHz

Waveform:	
Pulsewidth	0.1 μs
PRF	6 kHz
Receiver:	
Type	single conversion, with STC
Bandwidth Instantaneous	10 MHz
Noise Factor	4 dB
Tuneability	200 MHz
Linearity	±2 dB over 70 dB range
Signal Processor:	
Functions	Quadrature channel A/Ds GMTI Thresholding ECCM Target Reporting
Improvement Factor	40 dB
Visibility Factor	12 dB
Dwell Time	24 ms.
Non-coherent integration	141 pulses
Control and Data Processing: Type	Microprocessor
Modes	Turn-on/turn-off Schedule Data Formatting Test
Software	On-board

2.7.3.2 Synthetic Aperture Radar (SAR)

An example of a radar that provides high resolution mapping of the ground terrain is a battlefield surveillance radar mounted on a remote piloted vehicle (RPV). The purpose of this radar is to acquire high resolution imagery of a battlefield area for the purposes of detecting armored vehicles, aircraft on runways, troop concentrations, etc. It is usually required that the imagery be calibrated in ground coordinates (i.e., latitude and longitude, or the equivalent) to allow accurate location of observed features.

A side-looking synthetic aperture radar (SAR) provides these functions. The radar antenna looks sideways, perpendicular to the flight path of the vehicle, illuminating a swath to the side of the flight path. High resolution in range is obtained through use of a wideband transmitted signal waveform. High resolution in azimuth is obtained through doppler processing of the signals returned during a coherent dwell time. A number of images made sequentially with different radar frequencies are typically combined together non-coherently to improve the image quality and to remove specular scintillation effects.

A significant aspect of a high resolution synthetic aperture radar is the need for motion compensation. Deviations of the flight of the aircraft from a straight line path will lead to variations in the radar line-of-sight path length. These variations, if not compensated, will induce phase errors that degrade the image resolution. Compensation requires an inertial measurement unit on the vehicle to monitor the vehicle motion and to sense the departure from straight line motion. The outputs of this inertial measurement unit are then utilized by the radar control processor to compute phase shift commands to be applied in the signal processor to compensate for the non-ideal motion.

The data provided by the inertial measurement unit also allow the flight path of the vehicle in ground coordinates to be monitored. This, in connection with the radar measurements, permits calibration of the ground coordinates of the imagery.

In Table 2.7.5, the characteristics of a typical high resolution SAR radar are summarized. This radar provides a resolution of 1 meter for imaging out 20 km from the flight path. It utilizes a circular flat plate antenna 0.3 meters in diameter mounted on the side of the RPV. It requires only modest power (25 watts average) to provide high S/N on very low reflectivity terrain such as runways, highways, etc.

The resulting imagery can be either stored on board the vehicle for later retrieval when the RPV returns to its base, or can be relayed back to the base by a microwave communication link, for example.

TABLE 2.7.5 RPV-Based Battlefield Surveillance Radar	
Assumptions:	
Radar Type	Side-looking synthetic aperture radar
Mapping Range	20 km from flight path
Mapping Resolution	1 meter
RPV velocity	250 m/s
Terrain reflectivity (min)	-25 dB m^2/m^2
Characteristics:	
Wavelength	3 cm
Antenna	
Type	Flat plate array
Dimensions	0.30 m dia
No. Of elements	79
Gain	30 Db
Polarization	Horizontal
Sidelobes	- 35 dB peak, - 45 dB rms
Transmitter	
Type	TWT or solid state
Peak power	15 kW
Avg. power	25 W
Tunable bandwidth	600 MHz (frequency diversity)
Pulsewidth	0.7 μs
Pulse compression	100:1
PRF	26 khZ
Receiver	
Type	Double conversion, single channel
Bandwidth	150 MHz
Noise factor	5 dB
Tunability	600 Mhz
Linearity	±1 dB over 100 dB range

TABLE 2.7.5 RPV-Based Battlefield Surveillance Radar	
Signal Processor	
Functions	Quadrature channel A/D Pulse Compression (FFT) Motion Compensation Azimuth Compression (FFT) Multi-look integration
Coherent dwell time	1.6 s
Non-coherent integration	4 looks
Control Processor	
Functions	Radar turn-on scheduling Frequency diversity control Motion compensation control Map recording

2.8 Test Procedures for Example Radars

This section describes test procedures for testing the artillery locator radar and the RPV-based SAR described above. Test procedures for vulnerability to intercept and radar accuracy measurement are also described.

2.8.1 Test Procedures for Artillery Locator Radar

This radar has been chosen as an example for describing a representative test plan and the pertinent test procedures and required facilities. The selection is based upon the fact that this radar is representative of a sophisticated digitally-controlled multi-mode radar incorporating an electronically-scanned-array, pulse-doppler waveforms, programmable digital signal processing, and programmable data processing and display. It is the most complex of the example radars described above, and the test procedures and facilities required will suffice for testing of the other example radars. Exceptions to the latter statement would of course, include the flight testing of the airborne radars. These exceptions are covered in Section 2.6.1.1.

Fig. 2.8.1 shows the typical flow of a radar system-level test program. The closed loop tests are selected to be accomplished first (unless facility unavailability dictates different scheduling) to allow test personnel to become thoroughly familiar with the major subsystems and their operation one step at a time. These tests are shown to be done in parallel, the radar may not break down physically to allow the antenna to be at the pattern range, while the closed-loop tests proceed at other test sites (e.g. the EMC testing facility). In the latter case, the complete radar may have to be moved from site to site to conduct the various tests.

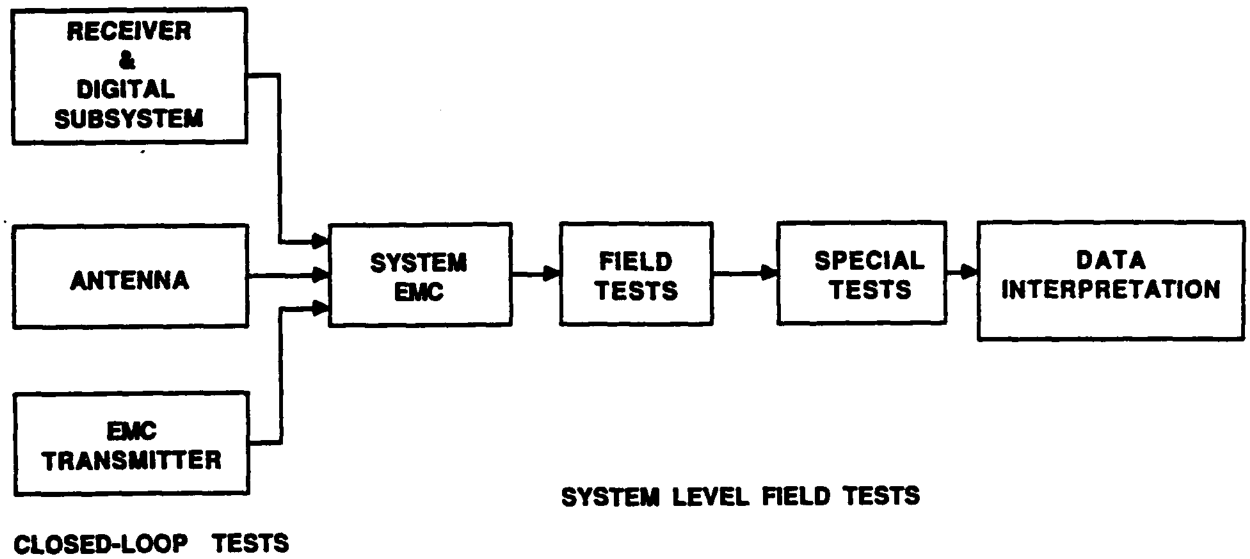


FIGURE 2.8.1 TYPICAL FLOW OF TEST PROGRAM

The following closed-loop tests (described in Section 2.5) would be conducted on the receiver and digital subsystem:

(a) Velocity response (Test 2.3)

(b) Target acquisition time (Test 3.1)

(c) Simultaneous target handling capacity (Test 4.1)

(d) Doppler resolution (Test 5.2)

(e) Range and doppler tracking accuracy (Test 6.3)

At the antenna pattern measurement facility (preferably, the compact range), the antenna patterns would be measured as described as Test 5.4 in section 2.5.3.7. Cardinal plane cuts should be taken for the beam positioned at boresight (normal to the array face) and at the corners of coverage (± 45° azimuth and ±7.5° elevation). Sum beam and both (azimuth and elevation) difference beam patterns should be measured. At least one cut (e.g. at azimuth boresight beam position) should be taken at the elevation angle corresponding to the level-terrain horizon when the radar is sited for normal operation (probably 4° or 5° below boresight). In all cases, but especially the latter case, the sidelobe levels (especially, in the azimuth plane) are of strong interest with respect to ECM vulnerability.

Mainbeam characteristics of interest include: beamwidths, relative gains for the various scan angles, and difference pattern null depths. Beamwidths will vary (broadening) with electronic scanning off boresight and relative gains will decrease with scanning off boresight. For the radar described here, the beam broadening should be 40% and the gain loss would be less than 2dB. Difference in pattern null depth requirements relate to angular accuracy requirements and for the accuracies required of this radar, values in the vicinity of -30dB would be required.

Angular resolution (antenna beamwidth) measurements do not typically need to be measured to better than ± 5%, since real-beam resolution is not usually a critical factor of radar performance. With a 1.5° minimum (elevation) beamwidth, the precision of antenna (or radar unit) positioning relative to the signal source would then have to be within 0.07° over an angular change of less than 5°. Absolute accuracy is not of concern to these (resolution) measurements.

The in-band EMC tests with the transmitter (Test 7.1) are shown in Figure 2.8.1 within a dashed-line box, since they could be conducted at the EMC test facility in parallel with the other closed-loop tests if the transmitter subsystem is separable from the other

radar subsystems. If it is not separable, these tests would be included with the other EMC tests (the remainder of test no. 7.1 and test no. 7.2), when the complete radar system is at the EMC test facility.

The overall system EMC tests are shown in Figure 2.8.1 as preceding the field tests. They could follow the field tests, if facilities scheduling would be better served.

Field tests would be conducted at a test site that has the following characteristics:

1. Unobstructed view toward area where the test target (aircraft) will operate.

2. Moderately rough terrain (e.g. plowed fields, heavy grass, or brush covered) in the foreground, to minimize forward reflected propogation as would be experienced over water.

3. Strong isolated point of clutter within field of view and at a range beyond radar antenna near field as well as the minimum range capability of the radar (as determined by the transmitted pulsewidth and receiver circuit recovery time). This clutter would be used for SCV measurements.

4. A boresight tower should be placed within the field of view and beyond the near field of the radar antenna ($R > 2D^2/\lambda$, where D is the maximum antenna aperture dimension and λ is the wavelength).

5. It should be possible to position the mobile EMETF and other jammer simulators (or jammers) in the foreground. If sidelobe cancellers are incorporated in the radar, it should be possible to position jammer simulators (noise sources) beyond the near field of the radar antenna.

The following tests would be conducted at this field site in accordance with the procedures of Section 2.6.

a. Detection range and coverage (Test 1.1)
b. SCV (Test 2.1)
c. Range resolution (Test 5.1)
d. Angle accuracy (Test 6.1)
e. ECM vulnerability (Tests 8.1 and 8.2)
f. ARM susceptibility (Test 8.4)
g. Target discrimination (Multiple-time-around target rejection part of Test 9.1)

In the case of the artillery locator, the Special Tests of Figure 2.8.1 would be field tests with live mortar rounds. These tests would be conducted at a different site than that above, and would be located in the vicinity of an artillery firing range.

These tests would include:

a. Detection and tracking of live artillery rounds, fired at various quadrant elevation angles and for various ranges. Trajectories should be through the corners of the radar coverage volume, with impact zones within the hypothetical area of protection. Tracking and prediction accuracies should be determined by comparing the radar predicted weapon locations with the actual surveyed locations. At least two types of artillery pieces should be used (e.g. 105 mm and 155 mm).

b. Multiple target handling capabilities of the radar can be verified with multiple and rapid firing weapons.

c. Target discrimination capabilities of the radar with regard to mortar rounds, aircraft, and other non-artillery targets can also be evaluated at this test site (e.g. mix mortar firings with artillery firings.). Aircraft targets would obviously be flown over this range when no live firings are taking place.

Evaluation of the test data would be on the basis of the radar's ability to provide the specified detection coverage volume, achieve the specified SCV, handle the multiple target requirements, discriminate against unwanted targets, cope with the ECM threat, and achieve the specified prediction accuracy. Any shortcomings in these areas should be evaluated with regard to their influence on mission effectiveness.

2.8.2 Test Design for Radar Accuracy

Search, tracking and mapping radars are all required to produce output data which has certain accuracies with respect to an external reference coordinate system. The objectives of system tests for accuracy are to validate the radar error model which has previously been formulated on the basis of analysis and subsystem tests. The example of an artillery locator radar system is used here to make the test design more definite.

The artillery locator radar system is designed to scan a region 2-3° above the horizon out to a range of some 30 km. Upon detecting a target, the radar places a track beam, interleaved in time with the search beams, onto the target and performs a monopulse track for several seconds. The tracking data are converted to Cartesian coordinates, smoothed,

and applied to estimation of a trajectory. The weapon is assumed to be located at the origin of this trajectory. The intended accuracy of weapon location is 15 m CEP, including effects of terrain slopes and alignment of the radar to the reference coordinate system. As a result, smoothed tracking accuracies of a few meters in range and tenths of one milliradian in angle are required.

In order to establish the objectives of a particular test, we must first define the operational conditions to be simulated in the test:

(a) Type of weapon.
(b) Type of trajectory.
(c) Electronic and clutter environment.

The test objective is then to measure the radar system accuracy in a particular combination of these three conditions.

General Test Procedures

The general test procedures must now be defined, based on the test objectives.

Boresight Tower Test for Angle Accuracy (Test 6.1). Define the following test conditions:

(a) Location of the tower from the radar.
(b) Orientation of the radar array from the tower.
(c) Signal power and fluctuation to be generated at the boresight tower.
(d) The nature of the terrain between the radar and the tower, as it affects multipath error.
(e) The signal environment to be modeled at the radar; clutter, ECM, and friendly interference.

Boresight Tower Test for Range and Doppler Accuracy (Test 6.3). Define the following test conditions:

(a) Range and doppler shift vs. time.
(b) Signal strength and fluctuation.
(c) The signal environment at the radar receiver; clutter, ECM and friendly interference.

Live Firing Test for Radar Accuracy (Test 6.2). Define the following test conditions:

(a) Specific type of projectile (e.g., 105-mm shell).
(b) Trajectory: muzzle velocity, quadrant elevation, azimuth from weapon.
(c) Location of weapon from radar: range and azimuth.
(d) Radar siting, assigned scan sector, and terrain characteristics.
(e) Friendly signal environment in the band of radar operation.
(f) Hostile signal environment in the band of radar operation.
(g) Other instrumentation (e.g., wind measurement, impact location).
(h) Data recording facilities and methods.
(i) Real-time monitoring of test conduct results.
(j) Data reduction, interpretation, and validation of test.

From (e) and (f) the location, type, and schedule of signal environment simulators is prepared.

2.8.3 Test Design for Vulnerability to Intercept

Hostile action against radars can take the form of active ECM, passive ECM, evasion, or physical attack (e.g., use of ARM's). In order to initiate this action, the presence and operational state of the radar must be determined by the attacker, using either intelligence sources or real-time signal intercept. Both these sources of data may be inhibited by use of radar waveforms and operating procedures which reduce the probability of signal intercept. Certain modern radars are designated as having low probability of intercept (LPI) features, some of which are common to conventional radars and others are unique to the LPI radar system. The purpose of this test is to evaluate the vulnerability of either type of radar to intercept of its signal by an ESM receiving system, and to location of the radar on the basis of this intercept data, in a realistic environment.

2.8.3.1 Definition of Test Objectives

The radar under test can always escape intercept if it fails to radiate a signal. The steps in defining the test objective are as follows:

Establish the normal operating mode or modes of the radar.

The radar specification must be reviewed to determine the characteristics of these modes, and to define the modes in which the radar is to operate during the test. This data will include the following:

(a) Transmitted waveform parameters.
(b) Antenna scan parameters.
(c) Durations of radar emissions.

Define the environment (physical and electronic) in which the vulnerability of the radar is to be assessed.

(a) Radar siting and terrain characteristics.
(b) Associated vehicles and electronic equipment which may affect the ability of the ESM system to locate and identify the radar.
(c) Friendly signal environment in the band of radar operation and adjacent bands; Relative location, frequency and power of signal sources.

Define the location and type of ESM system against which the vulnerability is to be assessed. Prior analysis of the radar and its intended operational environment is required to establish reasonable or expected values for ESM location and type. For example, in the case of a weapons location radar, the ESM may be land-based at ranges of 15 to 35 km, or airborne at 15 to 100 km. The conventional intercept receiver of today, optimized for radar signals used over the past several decades, can be expected to achieve high probability of intercept on those signals, but not on new types or signal used in LPI radars. Wiley [9] has discussed the approaches to design of intercept receivers for LPI waveforms, and at some time in the future it may be necessary to test both conventional and LPI radars against both conventional and new intercept receiver designs. The ESM system characteristics to be specified for test are as follows:

(a) Range and altitude of receiver.
(b) Intervening terrain features.
(c) Type of antenna and scan or printing angle.
(d) Type of receiver and *a priori* data available to operator.

Define the time scale of the intercept operation (given enough time, most radars can be intercepted and located even when the probability of signal intercept is low for a given observation): Desired probability of intercept = P_i in t_i seconds. Prior analysis of the radar and ESM system is required to establish reasonable or expected values of probability and time.

Define the objective of the intercept system in radar location: Desired accuracy of location σ_θ or $\sigma_{x,y,z}$ in t_o seconds. Prior analysis of the radar and ESM system is needed to establish reasonable values of accuracy and time.

2.8.3.2 General Test Procedures

The general test procedures must now be defined, based on the test objectives.

1. Radar location and schedule of operation.
2. ESM system location and schedule of operation.
3. Location, type and schedule of signal environment simulators.
4. Other instrumentation (e.g., tracking of airborne platforms).
5. Pre-test briefing of operating personnel.
6. Data recording facilities and methods.
7. Real-time monitoring of test conduct and results.
8. Data reduction, interpretation, and validation of test.

2.8.4 Test Procedures for RPV-Based Battlefield Surveillance Radar

System level testing of a synthetic aperture radar (SAR) is devoted primarily to verifying that the radar imaging capabilities satisfy the specifications. The characteristics that must be verified include:

- resolution
- field of view
- mapping accuracy
- sensitivity

The imaging technique of SAR requires forward motion of the platform to sweep out the synthetic aperture that provides the azimuthal resolution. Furthermore, the quality of the resulting imagery depends to a great extent on the accuracy with which the motion compensation function in the radar measures and corrects for departures from a straight, constant velocity motion. Therefore, it is not possible to make significant tests of the imaging capability of SAR by bench tests in the laboratory.

The most useful approach to system testing of these radars is to fly them in the field against calibrated test scenes. A number of different test scenes are usually required. One scene provides resolution measurement, another provides dynamic range and sensitivity measurement, while others provide realistic targets for image quality assessment.

A test scene for measuring the resolution capabilities of the radar consists of an array of radar reflectors aligned in a cross (or ell) formation on the ground. The alignment is oriented relative to the flight path so that one row of reflectors is along the range dimension of the resulting imagery, while the other row is along the transverse dimension (the doppler or azimuth dimension). The spacing of reflectors along each row is made non uniform.

The spacing of the closest pair of reflectors is made equal to the specified resolution, with other pairs having increasing spacings. Corner reflectors or Luneburg lens reflectors can be used in these arrays, however care must be taken to orient their direction of high reflectivity relative to the flight path so that they are visible to the radar. The test scene is flown over and imaged, and the resulting imagery is analyzed to verify that the specified resolution is obtained in each coordinate. The Radar Spoke/Resolution Facility ("Spoke" Facility) at USAEPG represents such a capability.

A test scene for measuring the sensitivity and dynamic range of the SAR consists of an array of reflectors of varying sizes, ranging from a minimum of approximately 1.0 m^2 or less, up to 100 m^2 or more. These reflectors are placed in a cross (or V) orientation aligned with the range and doppler coordinates of the SAR imagery so that any signal saturation or suppression effects caused by saturation in the receiver or signal processor will be observed. These effects are visible in the imagery as either (a) dark bands of suppressed signals extending to either side of the image of a large reflector, or (b) doubled or paired images of some of the smaller reflectors surrounding the image of a large reflector (i.e., mirror images).

Coordinate scaling nonlinearities and skewing in the imagery can be measured using a test scene consisting of a set of radial lines of reflectors. A useful arrangement for this purpose consists of a set of eight spokes radiating outward at 45 degree increments in bearing and extending as far as practicable relative to the size of imagery to be generated. The imagery of this test scene is analyzed to determine the accuracy of scaling throughout the image area.

More elaborate test scenes can be used to verify the functional capability of the radar to provide the types of data and information intended for its tactical applications. A test scene containing a large number of armored and other tactical military vehicles and weapons (the Barstow Array) has been established by the U.S. Army at Barstow, California. This well documented test array is extremely useful for evaluating the suitability of the SAR imagery to support the detection and classification of targets by human (or computer based) imagery analysis. Another very useful set of test scenes (the North East Test Area) has been established in the region near Griffiths Air Force Base in New York State. This set of scenes contains examples of various tactical (and strategic) target complexes such as a coal-fired power plant, a hydro-electric plant, a set of runways, a warehouse area, and permits the assessment of the SAR image quality for these military significant and complex scenes.

2.9 Test Data Recording and Evaluation

Closed-loop testing described in Section 2.5 above is based on the use of a Computer Aided Testing (CAT) approach which is organized around a desk top computer with its common peripherals [10]. A typical configuration would include the following: computer, keyboard, monitor, printer/plotter, operation system, internal RAM, hard disk, communications interface, high level program language compiler, and I/O devices that are compatible with the radar test point terminations.

Data recording, analysis and evaluation are accomplished by appropriate software written to implement the required functions. In the case of analysis and evaluation are accomplished by appropriate software written to implement the required functions. In the case of analysis of test data, off-the-shelf math packages are available that can perform most of the analysis required for radar evaluation.

One issue that requires careful consideration is that of speed compatibility. Large amounts of real time data manipulation will force some partitioning of computer tasks into an off-line mode. Off-line data processing can be implemented in another computer or in the CAT computer at a later time so long as the test data have been captured in real time and stored on disk.

2.10 Test Equipment and Facilities

This section summarizes the test equipment and facilities requirements for conducting the tests described in Sections 2.5 and 2.6. Facilities available at Ft. Huachuca are identified, and representative commercially available test equipments are identified as candidates for conducting the tests on the representative radars described in Section 2.7.

2.10.1 Requirements

Table 2.10.1 summarizes the requirements for the closed-loop tests listed in Table 2.4.1 and described in Section 2.5

Table 2.10.2 summarizes the requirements for the field tests listed in Table 2.4.1 and described in Section 2.6. These tests should be conducted at a site which provides a clear view in the foreground, and the latter should be characterized by moderately rough terrain such as brush covered or plowed fields (as contrasted with smooth surfaces, such as over water, which will introduce a significant propagation factor due to surface reflection). Strong point clutter scatter should be within the field of view to permit SCV measurements, and a boresight tower should be available for tracking accuracy measurements.

TABLE 2.10.1 FACILITIES REQUIREMENTS FOR CLOSED-LOOP TESTS FACILITIES AND TEST EQUIPMENT						
	PC TYPE COMPUTER & PERIPHERALS & RECORDER	SIMULATED TARGET GENERATOR	ANTENNA PATTERN RANGE	SPECTRUM ANALYZERS	DUMMY LOAD	ECM SIMULATOR
	PREFERRED TESTS					
VELOCITY RESPONSE (NO. 2.3)	X	X				
TARGET ACQUISITION TIME (NO. 3.1)	X	X				
NUMBER OF SIMULTANEOUS TARGETS (NO. 4.1)	X	X				
DOPPLER RESOLUTION (NO. 5.2)	X	X				
ANGLE RESOLUTION (NO. 5.4)	X		X			
RANGE AND DOPPLER ACCURACY (NO. 6.3)	X	X				
EMC (NO. 7.1 + 7.2)				X	X	
	ALTERNATE TESTS					
RANGE RESOLUTION (NO. 5.3)	X	X				
VULNERABILITY TO ECM (NO. 8.3)	X					X
TARGET DISCRIMINATION (no. 9.2)	X	X (TAPE OR DISC PLAYER MAY BE REQUIRED FOR PRE-RECORDED TARGET SIGNATOR)				

TABLE 2.10.2 FACILITIES REQUIREMENTS FOR FIELD TESTS											
	P.C. TYPE COMPUTER	AUGMENTED TARGET	PHASE INTRO.& DRIVE OSCILLATOR	OSCILLOSCOPE	VARIABLE (MICROWAVE) ATTENUATOR	SIMULATED TARGET GENERATOR	BORESIGHT TOWER (+ SOURCE)	ECM SIMULATOR & NOISE & JAMMER	SPECIAL SIGNAL SOURCES	SPECIAL TARGETS	
	PREFERRED TESTS										
DETECTION RANGE (NO. 1.1)	X	X									
SCV (NO. 2.1)	X		X	X	X						STRONG POINT CLUTTER IN FAR FIELD
RANGE RESOLUTION (NO. 5.1)	X			X							STRONG POINT CLUTTER IN FAR FIELD
ANGLE ACCURACY (NO. 6.1)	X						X				
ECM (SPECIAL) (NO. 7.3)	X			X					X		
ECM VULNERABILITY (NO 8.1)	X	X						X			
ECM VULNERABILITY (TEST 8.2)	X	X							X*		*NOISE SOURCES
ARM SUSCEPTABILITY (NO. 8.4)	X	X				X*		X	X		WHEN C-L TEST
TARGET DISCRIMINATIO N (NO. 9.1)	X									X	

TABLE 2.10.2 FACILITIES REQUIREMENTS FOR FIELD TESTS											
AIRBORNE RADAR SCV (NO. 10.1)	X	X									ROOFTOP
AIRBORNE RADAR RESOLUTION (NO. 10.2	X									X*	PC ONBOARD. *TEST SCENES
	ALTERNATE TESTS										
SCV (NO. 2.2)	X			X	X	X					STRONG POINT TARGET IN FAR FIELD
ACQUISITION TIME (NO. 3.2)	X	X									
ACCURACY (NO. 6.2)	X	X									ITR REFER-ENCES

The site should not preclude the location of the mobile (non-communications) EMETF for the conduct of ECM vulnerability tests.

It can be seen that all of the tests with a modern digitally-controlled radar require a PC-type computer plus peripherals and recording equipment for control of the tests and data collection. In addition, test data processing (tabulating, plotting, statistical analysis, etc.) should be done with this computer or a compatible computer.

Test software will have to be prepared for the radar system to be tested. Also, interfaces between the PC and the radar will have to be established. These may be available through the radar control computer bus or the built-in-test (BIT) or fault isolation features of the radar. However, it is very likely that some special hardware and software will be required to effect the appropriate interfaces.

Airborne radar testing may not require a boresight tower for rooftop testing. Flight tests will require an aircraft equipped with an adequate IMU and sufficient on-board space to allow for the PC system and the test personnel as well as the radar. The test scenes for SAR testing could be the Fort Huachuca "Spoke" and "Dry Lake" facilities.

The final field tests for an artillery locator (or mortar locator) should involve live weapon firings. In this case, target discrimination techniques are expected to be based on trajectory analysis and multiple-time-around echoes. Hence, field tests should be planned on this basis and incorporate targets and firing conditions which are to be discriminated against.

The Fort Huachuca Instrumented Test Range (ITR) will provide an excellent reference for use in position accuracy measurements in any radar tests involving airborne targets or airborne radars which have position measurement features. (See [1] and [11].)

Special targets for conducting discrimination tests would be determined by the radar performance specification.

The number of noise sources required for test 8.2 should equal the maximum number of jammers called out in the specification.

To a large extent, the facilities required for evaluation of intercept vulnerability are available as by-products of existing EW test programs. For example, at USAEPG there are many types of ESM equipment, either under evaluation or in use as support equipment for other programs. The EMETF is equipped with advanced "stress loading" simulations to produce EM environments according to standardized scenarios for different military situations. While this equipment has been designed to test intercept receivers, communications receivers, and radar receivers, it can also serve as the background environment

for evaluation of vulnerability of the conventional or LPI radar system to intercept of its signals. Antenna test facilities, suitable for many varieties of radar antennas, are installed at AEPG.

The additional facilities needed for complete evaluation of LPI radar systems include the following:

(a) Special LPI waveform generators to simulate the signals from certain new radar designs, in closed-loop tests;

(b) Antenna pattern generators to simulate the low sidelobes of new antenna designs, in sectors far from the main lobe;

(c) Multipath scattering models to simulate the effects of a number standard terrain situations and radar siting options;

(d) Field test sites, chosen to represent these terrain situations, to validate the simulations and closed-loop test results on vulnerability to intercept;

(e) Generic airborne intercept and seeker receivers, to be used in the field tests to validate the indoor test results and to provide data on location and homing accuracy (not readily obtained through simulation and closed-loop testing);

(f) Field environment signal generators, to amplify and radiate the EM environment of the closed-loop models toward the airborne receivers during field tests involving the actual radar equipment.

2.10.2 Test Facilities - Available and Required

Tables 2.10.3 and 2.10.4 include brief descriptions of the facilities and test equipment identified in Section 2.10.1, together with the identification of typical available facilities and equipment as well as an indication of availability at USAEPG. Where question marks are shown, it is understood that equipments of the general types listed are at Fort Huachuca, but it is not known if these equipments would meet all of the requirements or if they would be available to a given radar testing program.

The configuration suggested in Section 2.5.1 for closed-loop testing is based on a signal simulator that injects various test signals, under computer control, into the receiver

and/or digital processor subsystems. A test control computer coordinates the test signal inputs and evaluates the radar performance by monitoring the processing and data results in the radar.

A suitable signal simulator is the Model HP-8770A Arbitrary Waveform Synthesizer of Hewlett-Packard [12]. This synthesizer together with a control computer and waveform synthesis software is termed the HP-8770S Signal Simulator System, [2]. Arbitrary waveforms in the frequency range of 0 to 50 MHz are define in the control computer using the software provided. They can then be stored on disk for later use and also downloaded to the signal simulator memory for immediate signal generation. The simulator can be programmed to interlace various waveforms from its memory in a flexible manner, thus providing a multiple target echo simulation capability.

TABLE 2.10.3 FACILITIES AND TEST EQUIPMENT FOR CLOSED-LOOP TESTS			
FACILITIES AND TEST EQUIPMENT	**DESCRIPTION**	**TYPICAL FACILITIES AND EQUIPMENT**	**AVAILABLE AT USAEPG**
PC TYPE COMPUTER	PC TYPE DESK-TOP COMPUTER PLUS PERIPHERALS (INCLUDING DISC MEMORY FOR DATA RECORDING) AND SOFTWARE	HP 200 OR 300 SERIES, OR IBM PC, ETC. [12, P.668]	?
SIMULATED TARGET GENERATOR	WAVEFORM SYNTHESIZER FOR INJECTION OF TARGET SIGNALS AT IF OR VIDEO	HP8770A [12, P. 364]	NO
ANTENNA PATTERN RANGE	COMPACT ANTENNA RANGE OR FAR-FIELD ANTENNA RANGE	GEORGIA TECH. COMPACT RANGE SYSTEMS	YES
SPECTRUM ANALYZER	COVER BANDS FROM MINIMUM VOLUME OF F_0 TO 3 F_0 OR 18GHZ WHICHEVER IS HIGHER (RESOLUTION 1 = MHZ)	HP3585A HP 7000 [12, P106, P.110]	?
DUMMY LOAD	MINIMUM FREQUENCY BAND EQUAL TO RADAR TIMETABLE BAND CENTERED AT FO. HANDLES AVERAGE POWER OF RADAR	MICROWAVE COMPONENTS SUPPLIERS	?
ECM SIMULATOR	GENERATE WIDE VARIETY OF SIMULATED JAMMING SIGNALS INCLUDING NOISE OF BANDWIDTH EQUAL TO RADAR TIMETABLE BAND	EMETF + NOISE SOURCES + JAMMERS	EMETF + (SOME) JAMMERS

TABLE 2.10.4 FACILITIES AND TEST EQUIPMENT FOR FIELD TESTS			
FACILITIES AND TEST EQUIPMENT	**DESCRIPTION**	**TYPICAL FACILITIES AND EQUIPMENT**	**AVAILABLE AT USAEPG**
PC-TYPE COMPUTER	PC TYPE DESK-TOP COMPUTER PLUS PERIPHERALS (INCLUDING DISC MEMORY FOR DATA RECORDING) AND SOFTWARE	HP 200 OR 300 SERIES, OR IBM PC, ETC. [12, P.668]	?
AUGMENTED TARGET	SMALL AIRCRAFT, AUGMENTED (RADAR CROSS SECTION) WITH LUNEBERG LENS REFLECTOR (>10 DB AUGMENTATION	LUNEBERG LENSES, EMERSON CUMMING CO.	AIRCRAFT - YES LENSES - ?
PHASE MODULATOR + OSCILLATOR	SPECIAL PHASE MODULATOR, AT FIRST IF, DRIVEN BY AUDIO OSCILLATOR (10HZ - 50 KHZ)	(SPECIAL)	NO
OSCILLOSCOPE	GENERAL PURPOSE OSCILLOSCOPE WITH BANDWIDTH OF AT LEAST 10 MHZ	HP54200A [12, P.52]	?
VARIABLE ATTENUATOR	MICROWAVE ATTENUATOR, 60DB VARIABLE RANGE, 1DB ACCURACY. BANDWIDTH = RADAR TUNING BAND	HP 33304B + 33305B [12, P.332]	?
SIMULATED TARGET GENERATOR	WAVEFORM SYNTHESIZER FOR INJECTION OF TARGET SIGNALS AT IF OR VIDEO	HP8770A [12, P.364]	NO
BORESIGHT TOWER + SOURCES	STRUCTURAL TOWER WITH MICROWAVE SIGNAL SOURCES PLUS AMPLIFIER AND HORN ANTENNA	HP8683D (SOURCE) + HP8349B [12, P. 366, P. 394]	TOWER - NO, SOURCE + AMPLIFIER + ANTENNA?
ECM SIMULATOR	GENERATE WIDE VARIETY OF SIMULATED JAMMING SIGNALS, INCLUDING NOISE OF BANDWIDTH EQUAL TO RADAR TUNEABLE BAND	EMETF + NOISE SOURCES + JAMMERS	EMETF + (SOME) JAMMERS
SPECIAL SIGNAL SOURCES	SEE TEXT	------------	NO

Detailed specifications and descriptions of the Hewlett Packard equipments are contained in [12]. This equipment supplies is by no means the only source for such equipments. However, the company offers a relatively complete line of equipment for such application, and it is taken to be representative of what is generally available.

The EMETF is described in [1] and [13]. The Compact Antenna Range (CATR) is described in [1, P.26] and presentation notes by Georgia Tech Research Institute, entitled, "Fort Huachuca Compact Range".

2.11 Conclusions and Recommendations

This study has developed a methodology for radar system testing and evaluation which organizes the test procedures into laboratory-type testing, or closed-loop tests, to characterize system performance in a fine-grain sense, and field tests to benchmark major system performance measures in a real-world environment. The result of such an approach should be the achievement of a thorough and quantitative evaluation of a radar system at minimum cost.

Emphasis has been placed on modern and future radar designs, with the recognition that such radars have and will have extensive digital technology incorporated in them. This digital technology is largely of general purpose nature, including a significant amount of software. Hence, one important conclusion is that PC-type computer systems will play an important role in radar system testing.

The evolving threat places increased emphasis on testing for ECM vulnerability, including the capabilities of radars designed to achieve low probability of intercept (LPI) to avoid being located and negated (e.g. by ARM missile attack).

A review of the requirements for facilities and test equipment to perform radar system tests, together with a review of Fort Huachuca facilities reveals that USAEPG offers some unique facilities. In particular, the EMETF (non-communication portion) provides a strong potential for testing for ECM vulnerability. Of special interest is the potential for its use in creating an electromagnetic background wherein intercept receivers or ARM seekers can be pitted against a radar system under test for LPI evaluation.

Other USAEPG facilities that are applicable to radar system testing include:

1. Compact Antenna Range - for low-sidelobe antenna pattern measurements.

2. Radar Geometric Fidelity Facility at "Dry Lake" - for mapping radar evaluation.

3. Radar "Spoke"/Resolution Facility - for evaluation for synthetic aperture radars (SARs).

4. Blacktail Facility - for EMC testing.

5. Instrumented Test Range (ITR) - for radar accuracy measurements.

In addition, the geography of Fort Huachuca suggests that excellent field test sites can be established for testing all radar types of interest to this study. The availability of flight test aircraft, the potential for live firing tests for weapons location system, and the favorable climate combine to enhance the potential of the Fort Huachuca area for these purposes.

It is recommended that a number of Test Operation Procedures (TOPs) be prepared for radar system testing, as follows:

1. Radar Receiver and Digital Subsystem Closed-loop Testing

2. Field Testing of Radar System Overall Performance

3. Testing Radar System Vulnerability to Active ECM

4. Testing Radar System LPI Performance

Item 1, above, would cover the tests described in Section 2.5.3 of this report. Item 2 would cover the tests described in Sections 2.6.1 through 2.6.7. Item 3 would cover Section 2.6.8, and item 4 would cover Section 2.6.9.

It is also recommended that a TOP be prepared (or modified) to cover radar antenna pattern measurements with the new compact antenna range.

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